THE UNIVERSITY OF ALBERTA

AN INVESTIGATION OF THE MICROBIAL FLORA OF SEWAGE STABILIZATION PONDS

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ABSTRACT

THE MICROBIAL FLORA IN THE SEWAGE LAGOONS OF ALBERTA

The stabilization of microorganisms under the influence of the natural environment within the sewage lagoon systems in the Edmonton region has been investigated.

Four groups of microorganisms were investigated for each lagoon system: (1) the aerobic bacteria at the $7^{o}C$, $20^{o}C$ and $37.5^{o}C$ incubation temperatures; (2) the anaerobic bacteria at the incubation temperature of $37.5^{o}C$; (3) the coliform bacteria incubated at $37.5^{o}C$; and (4) the algae.

Aerobic and anaerobic bacterial counts were determined by the Plate Count Method. The Most Probable Number of coliforms was determined. A microscopic determination of the total count of algae was done.

A standard period from November /58 to November /59 (when a standard routine of operation was maintained) was used to compare the different lagoon systems. All lagoons were compared at two periods during this time. The first period was in the late winter of 1959 and the second period was in the late summer of 1959.

The counts of microorganisms were used to compare the functional capacity of each lagoon system from the point of view of microbiology.

It was shown that continuously overflowing lagoon systems with too short a detention time did not reduce the number of aerobic and anaerobic bacteria.

The least reduction in the number of aerobic bacteria occurred in the single long detention lagoon system used for winter and summer storage.

The least reduction of the number of anaerobic bacteria occurred in the single long detention lagoon system used for winter storage and summer storage or summer overflow.

The greatest reduction in the number of aerobic, anaerobic and coliform bacteria occurred in a lagoon system consisting of a series of short detention lagoons used for storage in early winter and allowed to overflow through the late winter and summer.

The greatest reduction in the number of aerobic bacteria occurred in the lagoon with the greatest surface area when single long detention lagoon systems of different structural design and capacity were used for winter storage and summer overflow.

The reduction of the Most Probable Number of coliforms (greatest in a series of lagoons) was inadequate to meet Public Health Standards in any of the lagoon systems studied.

The total algae count remained high in all lagoon systems winter (under the ice) and summer.

TABLE OF CONTENTS

Title Page

Approval Page

Abstract

Acknowledgements

Table of Contents

List of Tables

List of Figures

Introduction

Experimental

Results

Summary

Appendix

Bibliography

	PAGE
Introduction	1
1. History of Lagooning	1
2. Theory of the Microbiological Function of a Sewage Lagoon	3
3. Scope and Purpose of the Present Work	14
Experimental	15
Materials and Methods	15
A. Sampling for the Microbial Specimen	15
B. Sampling for the Chemical Analyses	16
C. Laboratory Procedure	17

TABLE OF CONTENTS (Continued)

PAGE

D. Discussion 21

1. The Specific Discussion 21

2. The General Discussion 22

Results 23

The Specific Discussions 23

Holden Sewage Lagoon 28

Daysland Sewage Lagoon 36

Bruderheim Sewage Lagoon 43

Lacombe Sewage Lagoon 51

Stony Plain Sewage Lagoons 73

Drayton Valley Sewage Lagoons 86

The General Discussion 101

1. Structure and Operation of the Lagoons 101

2. Stabilization of the Microorganisms 101

3. The Comparison of the Microbial Populations of each Lagoon During the Standard Period from the Late Winter to Late Summer of 1959 102

I. A Single Lagoon 102

A. Standard Routine of Operation Throughout the Investigation 102

1. Holden 102

2. Daysland 103

TABLE OF CONTENTS (Continued) PAGE

B. Routine of Operation altered during the Investigation....... 103

1. Lacombe... 103

2. Bruderheim.. 103

11. A series of lagoons.................................. 104

A. Routine of Operation altered during the Investigation........... 104

1. Stony Plain.. 104

2. Drayton Valley 104

Summary... 107

Appendixes.. 109

Appendix A, The schedule of the sewage samples which were collected from each Lagoon....................... 109

Appendix B, Characters of the Lagoon........................... 111

Appendix C, Dimensions of the Sewage Lagoons.................. 113

Appendix D-1 Classification of the Lagoons based upon the standard routine of operation..................... 114

Appendix D-2 The Schedule of the routine of operation of each Lagoon during the investigation.................. 115

Appendix E : The dominant genera identified in each sewage lagoon:

Holden.. 116

Daysland.. 117

Bruderheim.. 118

TABLE OF CONTENTS (Continued) PAGE

Appendix E: The dominant genera identified in each sewage lagoon:

Lacombe 119

Stony Plain 120

Drayton Valley 121

Protozoa and Crustacea 122

Bibliography 123

LIST OF TABLES

Microbial Populations in each Sewage Lagoon :

TABLE	LAGOON	SAMPLE	PAGE
I	Holden	Top	23
II		Bottom	26
III	Daysland	Top	32
IV		Bottom	34
V			
	Bruderheim	Top	39
VI		Bottom	41
VII	Lacombe	Top	47
VIII		Bottom	49
IX	Stony Plain # 3	Top	68
X		Bottom	70
XI	Stony Plain # 4	Top	72
XII		Bottom	72
XIII	Drayton Valley # 1	Top	78
XIV		Bottom	78
XV	Drayton Valley # 2	Top	81
XVI		Bottom	81
XVII	Drayton Valley # 3	Top	83
XVIII		Bottom	83

LIST OF TABLES (Continued)

Environmental Factors Observed at Each Sewage Lagoon

TABLE	LAGOON	PAGE
XIX	Holden	90
XX	Daysland	92
XXI	Bruderheim	93
XXII	Lacombe	94
XXIII	Stony Plain # 1	96
XXIII	Stony Plain # 4	96
XXIV	Stony Plain # 3	97
XXV	Drayton Valley # 1	98
XXVI	Drayton Valley # 2	99
XXVII	Drayton Valley # 3	100

LIST OF FIGURES

Microbial Populations in each Sewage Lagoon :

TABLE	LAGOON	SAMPLE	PAGE
1	Holden	Top	25
2		Bottom	27
3	Daysland	Top	33
4		Bottom	35
5	Bruderheim	Top	40
6		Bottom	47
7	Lacombe	Top	48
8		Bottom	50

Bacterial Populations at the Incubation Temperatures:

9	Aerobes $7^{o}C$	Top	56
10		Bottom	57
11	Aerobes 20^{o} C	Top	58
12		Bottom	59
13	Aerobes $37.5^{o}C$	Top	60
14		Bottom	61
15	Anaerobes 37.5^{o} C	Top	62
16		Bottom	63
17	Coliforms 37.5^{o} C	Top	64
18		Bottom	65

LIST OF FIGURES (Continued)

TABLE		SAMPLE	PAGE
	Algal Populations of the Sewage Lagoons :		
19		Top	66
20		Bottom	67
	Microbial Populations in Each Sewage Lagoon :		
21	Stony Plain # 3	Top	69
22		Bottom	71
23	Drayton Valley # 1	Top	79
24		Bottom	80
25	Drayton Valley # 3	Top	84
26		Bottom	85
27	Drayton Valley # 2	Top	82
28		Bottom	82

INTRODUCTION

1. History of Lagooning:

Waste stabilization ponds are artificial ponds constructed for the treatment of sewage (human, animal and industrial) by a biological process. Biological processes in nature oxidize complex organic compounds to inorganic compounds through numerous biogeochemical cycles for their potential utilization by other living organisms. The stabilization of sewage is the complete oxidation of the organic matter to the simple inorganic compounds, carbon dioxide, water and sulfates, nitrates and phosphates through the influence of the biotic-abiotic interactions occurring within a treatment plant such as a lagoon. The completion of stabilization of the effluent of a lagoon depends upon the flocculation of the microorganisms and their subsequent separation from the liquid phase. (McKinney, R.E., 1956)

The first historical records come from Russia and China where the sewage was converted to fertilizer or used to cultivate fish. Organized knowledge concerning the adequate and efficient function of these ponds has developed only in the past 50 years in Germany, the Scandanavian countries, and the United States. (Fitzgerald, G.P., Rochlich, G.A., 1958).

Even though a recent doctoral thesis from Wisconsin states there is no history of lagooning as a sewage treatment system in Canada there have been functioning lagoons present here for over

25 years. (H. Masato Kaneshige, 1959). Almost every province has constructed lagoon sewage systems.

In both the Vancouver region of British Columbia and the Winnipeg region of Manitoba sewage lagoons have been constructed and the efficiency of the lagoon at Winnipeg has been studied. (Lackie, T.H. 1957). Saskatchewan has a lagoon which has been functioning for over 25 years. During this period, the lagoon has accumulated only 0.5 inches of sludge, as shown by dewatering, even though the BOD loading was 50 lbs. BOD/acre/day. (Schaeffer, J.F., 1957). In Alberta there are over 187 sewerage systems, and the majority, 114, use lagoons.

Intensified investigations of the microbiological populations present within the lagoons of Alberta were carried out from the spring of 1958 to the winter of 1960 throughout each season. This report presents the results of these investigations.

2. Theory Of The Microbiological Function Of A Sewage Lagoon

The fundamental autotrophic and heterotrophic components are the basic functional and structural features which are integrated within the lagoon. These basic functions and the organisms responsible for the processes are partially separated in space and time. The processes may be stratified or mixed within the body of water, or there may be considerable delay in the heterotrophic utilization of the products of the autotrophic organisms in the bottom of the lagoon.

Each component has individual predominant features. The autotrophic component carries out the fundamental radiant energy fixation, and utilizes simple inorganic compounds to synthesize complex organic substances. The heterotrophic component utilizes, rearranges, and decomposes the complex organic matter and releases simple inorganic compounds.

Different sources of energy are transformed by the organisms. By primary production (or the algal photosynthetic process) radiant energy is stored in the organic matter and oxygen is produced. Respiration by all the organisms oxidizes the "imported" and synthesized organic matter releasing the energy for their activities.

Four major constituents comprise and indicate the structural and functional aspects of the lagoon. (Odum 1957).

(1) The Abiotic Substances, i.e. , the non-living sewage materials composed of inorganic and organic compounds.

The organic compounds are mainly carbohydrates, proteins, lipids and trace compounds. For effective microbial metabolism there must be adequate amounts of P, N and C present. All vital nutrients are present but in different physical states. The actively growing organisms will absorb the organic matter in the dissolved state very rapidly since it is immediately available. The major part of the organic matter is in the solid state and unavailable since it is absorbed within the organisms or is part of the particulate matter within the suspended solids or in the sludge at the bottom. The intermediate colloidal state is involved in the equilibrium of the physical states of matter and may be dissolved by the organisms or by changes in physico-chemical factors or by the interactions of the organisms and their environment in the lagoon. The rate of release of the nutrients from the solid state is fundamental in the regulation of the rate of metabolic function within the lagoon.

Potentially there is a wide variation of the taxonomic groups of organisms present, but microorganisms such as the bacteria, fungi, and protozoa are the main inhabitants of the lagoon system. There are also higher animals such as rotifers, crustacea, insects and other animals present. (Even human swimmers.)

A functional ecological classification of the organisms is used without regard to the taxonomic species present.

(2) The Biotic Constituents i.e., the living constituents which may be subdivided into functional kingdoms arranged according to their nutritional type and their energy source.

(a) The Producers or Autotrophic Organisms.

In the lagoon these are the algae or phytoplankton floating in the body of water. The algae species present may be completely autotrophic and require simple inorganic nutrients or partially heterotrophic requiring simple organic "growth substances" which they cannot synthesize.

Organisms assimilating organic matter, the heterotrophic organisms, are placed in the last two major subdivisions.

(b) Consumers.

There are many organisms which ingest their food which are termed the consumers. These are the macroconsumers or animals. The protozoa are the simplest animals found in a lagoon. They ingest the bacteria to aid in clarifying the lagoon effluent. When the higher animals are present this indicates that the sewage has become highly stabilized and an excess of oxygen is occurring at all times. The rotifers can be used as indicators of a very high degree of purification of 95 to 100 percent. Insects and the crustaceans particularly daphnia grow well in the stabilized aerobic lagoons where they utilize the bacteria, fungi and algae as their major food source. (McKinney, R.E., 1956)

(c) Decomposers.

Finally there are the decomposers which are the micro-organisms or microconsumers. Taxonomically these are the bacteria and fungi. They are the parasites and saprophytes. They are relatively immobile since they are imbedded in the dead protoplasm and the other organic

wastes which they are decomposing. The bacteria are the basic biological units in this aerobic-anaerobic process. They have a biochemical specialization which involves both the ability to metabolize different organic compounds at high rates and to carry it out within different ranges of physico-chemical states such as the redox potential, temperature and oxygen tension. There are bacteria which metabolize the organic wastes and others which utilize the by-products of the first group of bacteria. There are obligate aerobes and anaerobes and facultative bacteria present. The intense metabolic activity is demonstrated by the great heat which an immense microbial population may generate. For example, the temperature increases during decomposition as was shown at Lake Mead when the temperature of the bottom mud was 6°C greater than the adjacent water. (ZoBell, Sissler, and Oppenheimer, 1953).

Under normal environmental conditions the fungi, though of secondary importance, will aid in the stabilization of the organic matter. The fungi may predominate under unusual conditions such as at low oxygen tension, at low pH, and with low nitrogen content.

The decomposition of the wastes results from the processes of bacterial and fungal assimilation. The decomposers function to stabilize the organic matter to produce nutrients and "growth substances" for other organisms. This is a vital function since the food energy stored in the organic matter is dispersed for use by the other organisms. The sewage wastes, the synthesized foods and the decomposition products, termed the

"available food" are utilized by the producers, the consumers and the decomposers immediately in their respiration or later (there is a lag before synthetic metabolism occurs) or exported in the lagoon effluent.

No single species of bacteria or fungi causes complete decomposition although each causes an extensive change in the chemical nature of the lagoon environment and functionsin the equilibrium which makes nutrients soluble and available to the other organisms. The chemical content and bottom sludge is largely determined by the organismal activity. The decomposition products are absorbed or remain in solution for the other organisms, or are exported in the effluent adding to the BOD. The microorganisms breakdown the waste constituents to different degrees and at different rates. The fats, sugars and proteins are the most readily assimilated; substances such as cellulose, lignin and hair and bone taking much longer. The sludge remaining (the humus which is the resistant organic compounds) is decomposed in two stages, First the rapid production of humus and then the slow mineralization or stabilization of the sludge. The decomposers thus have a broad function and ability under a wide variety of environmental conditions.

Microbial Metabolism

Cellular oxidation of organic matter will occur in a wide range of oxygen tensions. Respiration occurs under aerobic conditions; fermentation under anaerobic conditions. The cellular processes have a general outline with a stepwise process of substrate oxidation involving

enzyme chains which release energy at each step. Fermentation gives poor clarification and produces odors.

Most of the microorganisms have facultative respiratory systems which are active over a wide range of oxygen tension. The extremes are a few species which live best where oxygen saturation is either zero or maximal. The vast majority live between these extremes. In any case the stabilization of organic matter seems to become complete no matter what the oxygen tension. Dissolved oxygen is used only in the aerobic system in the euphotic zone. Chemically combined oxygen is used both aerobically and anaerobically for the stabilization of wastes in the euphotic and benthic zones. Thus the chemically combined oxygen is more important than dissolved oxygen to the microorganisms in the predominately anaerobic system. The anaerobic process may produce odors, but most end-products are less objectionable; ammonia, carbon dioxide, methane and water. There is complete degradation of the organic matter, but the principal difference between oxidative processes of aerobic metabolism and reductive processes of anaerobic metabolism is one of time rather than efficiency.

The facultative bacteria growing at different levels of oxygen tension will produce different end-products. An excessive BOD demand or an inadequate oxygenation of the sewage will cause the oxygen demand to exceed the supply and result in a lower oxygen tension. Under reduced oxygen levels, the metabolism does not proceed to carbon dioxide and

water, but stops with anaerobic glycolysis and the formation of organic alcohols, aldehydes and acids. If the system has an inadequate buffering capacity the organic acids depress the pH to the more favorable range for fungi and inhibit the optimal activity of the bacteria. For example, when an Aerobacter species is grown under aerobic or anaerobic conditions with glucose as the sole carbon source, different products are produced. Aerobic glycolysis yields bacterial protoplasm, carbon dioxide and heat. Anaerobic glycolysis yields protoplasm, a large series of organic compounds which are released to the lagoon environment, and much less heat is produced. The complete stabilization of the glucose also takes much longer.

The aerobic bacteria derive their oxygen from surface reaeration caused by wind and water currents over the large water surface area. New cells are synthesized by the algae when they absorb the excess soluble nitrogen and phosphorus released with the bacterial carbon dioxide. Photosynthetic oxygenation by algae increases the supply of oxygen in solution until there is an excess of dissolved oxygen which becomes available for the metabolism of the aerobic bacteria and other higher organisms.

The aerobic bacteria utilizing the oxygen may create anaerobic conditions in the polluted water by using the oxygen faster than it can diffuse into the medium. The bacterial stabilization of the wastes occurs primarily under anaerobic conditions since the surface reaeration and

photosynthetic oxygenation cannot satisfy the imposed BOD loading in the influent and which settles into the benthic region.

The algal population maintains moderate aerobic conditions during the daylight but anaerobic conditions develope during the night. This diurnal aerobic-anaerobic process combines the process of aerobic liquid waste stabilization and anaerobic sludge digestion into one system. The algae provide the dissolved oxygen, and maintain an alkaline pH and optimum redox potential.

Theoretically, the bacterial population required to remove the organic matter varies within wide limits. Most important are the young actively growing bacteria of relatively few numbers whose metabolism is primarily for synthesis of new organisms since their base food demand is low. The larger group of older bacteria utilizes the food for its standing crop and synthesizes only a few organisms to balance the dying ones. The younger population, entering the log phase, is purifying the waste water more rapidly by removing the organic nutrients. The larger population, in the resting stage, produces a lower quality effluent through the loss of dead organisms. A mean population of these two extremes is necessary for the practical efficient operation of the lagoon. (Hermann, E.R., Gloyna, E.F. 1957).

Dominant Organisms:

The algae and bacteria will predominate together as the most prominent microorganisms within the lagoon since they do not utilize

the same waste components but have a symbiotic metabolism; each using the others' metabolic by-products. Different portions of the algal-bacterial "lysis-synthesis" cycle for carbon are utilized. The relative populations of algae and bacteria through their metabolism stabilize the organic wastes, synthesize complex organic matter from the inorganic wastes, and complete the cycle by forming usuable organic matter from the organic wastes.

The Lagoon Is A Primitive System:

Only producers and decomposers are present, i.e., the algae and heterotrophic microorganisms. The lagoon is an "open" system wherein part of the basic food energy is "imported" and passed through a very short route of exchange from the producers to the decomposers. It is an inefficient system for the dissipation of food (organic matter) and energy. When the environment improves the macroconsumers such as the daphnia and other insects and larger animals will invade the lagoon. This invasion is influenced by the seasons and depends upon physico-chemical factors such as the pH and oxygen tension. The seasonal change in temperature has a limiting effect on the number of kinds of organisms present due to failure of some to successfully adapt to the northern climate. Thus only a few species are present and metabolically active within the lagoon. In the winter it is only those organisms surviving under the ice cover which are active. In the summer, insects and birds are added to the food cycle in the lagoons. In colder regions a greater duration of light

energy fixation may occur as a result of adaptation of the producer organisms to the colder climate and likewise increased utilization of organic matter by the consumers may occur.

In the lagoon photosynthesis predominates in the euphotic zone. Only part of the photosynthate, the oxygen, is immediately and directly used in the lower trophic levels by the saprophytic and benthic organisms. Much of the synthesized organic matter is eventually deposited in the bottom mud where a well defined heterotrophic system is developed. The bottom mud lacks the producers and the only source of energy is the organic matter deposited through gravity. The heterotrophic component is inadequate for complete decomposition or stabilization of the organic matter. The algal nutrients must be brought to the euphotic zone by water currents in order that the autotrophic component may be active photosynthetically and metabolically. The effluent will contain a large quantity of algae and bacteria as these are not removed in large single primitive pond systems. Wennstrom (1955) reports that a series of three ponds followed by a final pond equal in size to the first three has the most complete autotrophic-heterotrophic processes. In this system the fourth pond is used to cultivate crustaceans which utilize the algae for food. Thus in the summer months the effluent from the fourth pond is free of algae. The crustaceans act as fish food and aid in clarifying the receiving body of water. In addition a good fishing stream results.

Stratification In The Lagoon:

The decomposers in the lagoon have a wide distribution throughout the body of water. A large bacterial population is associated with the maximum phytoplankton abundance in the euphotic zone. However, a greater peak in bacterial population occurs at the bottom within the mud-water interphase which contains the maximum amount of "rejuvenated" inorganic matter. Primary decomposition occurs in the water mass, but is more pronounced in the sedimented sludge. With favorable temperature conditions decomposition in the body of water is rapid.

There is a partial vertical stratification in the lagoon of autotrophic and heterotrophic layers. Physically they are divided into the upper sunlight zone (euphotic) where the autotrophic organisms (algae) dominate, and a lower zone (regenerating-consumer) where the heterotrophic decomposers are dominant.

Populations representing thermal and oxygen tension ecotypes may show a moving stratification associated with daily and seasonal changes. Physico-chemical stratification will also affect population stratification.

Lagoon Metabolism:

The predominating type of metabolism may change with the season. During the "open" water season autotrophy predominates. In the winter heterotrophy may predominate under the ice cover.

3. Scope and Purpose of the Present Work:

The fundamental principles of the treatment of sewage by the lagooning method are still being formulated both from the microbiological and engineering viewpoint. To date no comprehensive study of the microbial populations present in sewage lagoons located in the northern latitudes has been published. Since such information is necessary for the efficient operation and function of these lagoons the present investigation was undertaken.

Relationships between numbers of viable aerobic and anaerobic bacteria, coliforms and algae present in lagoons located in an area surrounding Edmonton were determined for all seasons of the year. The effect of environmental factors such as temperature, oxygen tension and pH in these relationships has been studied.

Potential public health hazard from lagoon effluents throughout the year was measured by determining the efficiency of elimination of pollution indicators, namely the coliform bacteria.

From an engineering point of view another purpose of this study was to determine what type of lagoon and what arrangement of lagoons stabilizes sewage best in northern latitudes where the temperature ranges from 25°C to 0°C in the lagoon and an ice cover of 3 to 4 feet forms in the winter season.

EXPERIMENTAL

Materials and Methods

A. Sampling For The Microbial Specimen

Apparatus

a) The Sampling Bottle:

The container was a 100 milliliter wide-mouth bottle with a 2-hole rubber stopper. Two glass tubes, one short and one long, extended through the stopper into the bottle. A long and a short rubber tube were attached to the external ends of the glass tubes. A U-tube of glass was placed into the longer rubber tube. Cotton plugs were placed in the end of this glass tube and the other rubber tube. The sample bottle was sterilized in the autoclave at 121^{o}C for 20 minutes. At the time of sampling the cotton plugs were removed and the free end of the glass tube inserted into the other rubber tube. The bottle was placed in the sampler cup.

b) The Sampler:

The sampler consisted of a long pole and a metal cup to hold the sample bottle and a mercury thermometer. The handle was a six foot metal tube marked off in feet. When the sample bottle was in the holder a mechanism was used to break the U-glass tube to allow the sewage fluid to drain into the bottle at the desired depth. At the same time the temperature of the lagoon fluid was measured.

Sampling Routine:

a) Seasonal:

During the winter a hole was chipped through the ice to obtain the sewage liquid.

b) Number of Samples:

At each sampling date two samples were taken. One was taken at a depth of one foot below the water surface. The other sample was taken about six inches above the bottom of the lagoon within the body of water. The depth of water and ice cover governed whether or not both samples were taken each time.

The temperature at the top and the bottom of the lagoon was measured at the same time as the sample was obtained.

c) Position:

The sampling position was close to the outlet region in most cases, though the ice cover caused the sample to be taken farther from the shore. In two lagoons the sample was obtained from the body of the water by using a raft.

d) Sampling Frequency:

Samples were taken weekly at the beginning of the investigation. Later they were taken monthly, bimonthly, seasonally or randomly.

B. Sampling For The Chemical Analyses:

The sewage sample was collected at half the depth of the lagoon fluid.

a) pH:

A portable pH meter was used at the lagoon site.

b) Dissolved Oxygen:

The content of free oxygen was determined by the modified Winkler Method which measures to 0.1 ppm of oxygen.

c) Additionally, weather conditions and the time of day were recorded.

C. Laboratory Procedure:

The Bacteria.

a) Methods of Diluting the Sewage Sample For The Viable Bacteria Counts.

The viable counts of the bacteria from the sewage sample were determined by the following methods. A pipette was used to add one milliliter of sewage fluid to nine milliliters of a sterilized distilled water blank to bring the test tube contents to ten milliliters, thus giving a 1 in 10 dilution of the sewage sample. Each time the sample was diluted it was shaken twenty times to distribute the bacteria. Serial dilutions of the sewage sample were carried out by transferring one milliliter of the initial dilution through serial dilutions in nine milliliter water blanks to obtain the necessary ten-fold dilutions. For all incubation temperatures, the dilution series was carried out to 1 in 10^6 dilutions. A pipette was used to inoculate the appropriate medium with a one milliliter aliquot from each dilution of the series.

The Coliform Count. (The Presumptive Test)

The Most Probable Number Index was determined as outlined in Standard Methods. (Standard Methods, 1955). Three series of sample dilutions, diluted to 1 in 10, 1 in 100 and 1 in 1000 were inoculated to five test tubes of Double Strength Lactose Broth for each dilution. Depending upon the results of previous tests on the samples from the same source greater or lesser dilutions were used for the three series of sample dilutions.

b) The Plating and Incubation Method for the Viable Bacteria Counts:

(i) The Aerobic Counts:

Pour plates of Difco Plate Count Agar were prepared with one milliliter of each dilution for each sample. One series of pour plates for each sample was incubated at 37.5°C for 48 hours under aerobic conditions. A second and third dilution series of pour plates were poured for each sample. They were incubated at 20°C for 72 hours for the second series and at 7°C for 7 days for the third series.

(ii) The Anaerobic Count:

A series of dilution pour plates in Difco Plate Count Agar were incubated at 37.5°C for 72 hours under anaerobic conditions.

(iii) The Coliform Count:

The culture tubes were incubated at 37.5°C for 24 and 48 hours. The culture tubes were examined for acid and gas production, and the number of positives for each dilution were recorded.

c) The Counting Method for the Viable Bacteria Counts:

i) The Aerobic and Anaerobic Bacteria:

The Viable Bacteria Count was determined by a visual count of the colonies growing on the solid medium by using the Quebec Colony Counter. The plates containing 30 to 300 colonies were counted and the resultant number multiplied by the dilution factor to determine the viable count at each temperature of incubation.

ii) The Coliform Bacteria:

The Most Probable Number Index was determined from the chart in Standard Methods (1955) after considering the number of positive acid and gas tubes in each dilution at 24 and 48 hours.

d) Other Bacterial Tests:

Pathogenic Organisms:

i) One milliliter of a 1 in 10 dilution of each sample was inoculated to single plates of MacConkey's and Bismuth Sulfite Agar Plates. These were incubated at 37.5°C for 24 hours.

ii) Non-lactose fermenting colonies were picked and transferred to the following media for incubation at 37.5°C for 24 hours: broths of lactose, dextrose, mannose, sucrose, dextrose-phosphate and peptone-water. A TSI slant was inoculated.

iii) Agar slants of the isolated colony were stored in the refrigerator and freeze-dried cultures were prepared later.

The Confirmed Test for Coliform Bacteria:

Confirmation was determined by isolating coliform bacteria colonies on the incubation of Eosine Methylene Blue Agar plates at 37.5°C for 24 hours.

The Algae

The Petroff-Hausser Counting Chamber was used to determine the total count of algae present. The dominant genera were identified. Other organisms were identified when present.

D. Discussions.

1. The Specific Discussions:

As a basis for discussion, the microbial populations of the top and bottom samples of each sampling date are averaged. When only a single sample either from the top or bottom of the lagoon is taken the microbial counts determined for this sample are used. Microbial counts which differ markedly from the previous and subsequent counts for the same lagoon are discarded since they are considered to be due to experimental error. Each microbial count is approximated to the nearest power to the base 10. The latter is used to describe the population curves.

Whenever the dilution of the sample is inadequate to determine the Most Probable Number of coliforms the previous and subsequent counts are considered to determine an approximate value.

The environmental factors are considered in relation to microbial populations.

2. The General Discussion:

All of the lagoons will be compared for their functional changes from the microbiological point of view during a Standard Period of investigation. This period lasts for 12 months between the times of drainage in November of each year (from November/58 to November/59). This is the period during which there is no change in the method of operating the lagoon. The microbial populations of all lagoons are compared during this standard period, specifically for the late winter of 1959 from February 17 to March 10/59, and the late summer of 1959 from August 25 to September 16/59, to show their relative functional capacity.

Microbial populations are discussed in 4 distinct groups. The bacteria are considered in 3 groups: (i) the sum of the aerobes at incubation temperatures. 7°C, 20°C, and 37.5°C; (ii) the anaerobes; (iii) the coliform group. Finally the total count of algae is given.

TABLE I

MICROBIAL POPULATIONS IN THE HOLDEN SEWAGE LAGOON

(Viable Bacteria Count /ml. Total Algae Count /ml.)

TOP SAMPLE

BACTERIA: AEROBIC	1958 JUNE 4	JUNE 17	JUNE 24	JUNE 25	JUNE 25	JULY 4
7°C	unknown	unknown	4.2×10^{5}	2.5×10^{5}	3.4×10^{5}	4.3×10^{5}
20°C	1.4×10^{7}	4.0×10^{5}	3.0×10^{5}	3.3×10^{5}	6.0×10^{5}	7.5×10^{5}
37°C	2.1×10^{6}	9.4×10^{4}	7.2×10^{4}	6.7×10^{4}	5.2×10^{4}	9.6×10^{4}
ANAEROBIC 37°C	$>3.0\times10^{4}$	6.0×10^{3}	2.7×10^{3}	2.7×10^{3}	1.2×10^{3}	1.8×10^{4}
COLIFORMS:	3.5×10^{2}	1.3×10^{2}	1.6×10^{3}	5.4×10^{2}	1.6×10^{3}	1.7×10^{2}
ALGAE:	2.0×10^{6}	9.0×10^{5}	8.5×10^{5}	9.5×10^{5}	5.0×10^{5}	4.5×10^{5}

BACTERIA: AEROBIC	JULY 18	JULY 30	AUG 15	SEPT 4	SEPT 24	OCT 21
7°C	6.5×10^{5}	1.5×10^{5}	3.6×10^{4}	4.9×10^{4}	1.2×10^{4}	3.6×10^{4}
20°C	4.2×10^{5}	3.7×10^{5}	5.2×10^{4}	2.7×10^{5}	2.1×10^{4}	1.8×10^{5}
37°C	1.3×10^{5}	1.8×10^{5}	1.7×10^{4}	2.6×10^{5}	4.0×10^{3}	2.0×10^{4}
ANAEROBIC 37°C	9.0×10^{3}	3.3×10^{2}	5.0×10^{2}	1.1×10^{3}	5.0×10^{3}	6.0×10^{3}
COLIFORMS:	2.1×10^{1}	$>2.4\times10^{3}$	1.1×10^{2}	5.4×10^{2}	3.5×10^{2}	$>2.4\times10^{3}$
ALGAE:	3.0×10^{5}	3.0×10^{5}	1.2×10^{6}	1.1×10^{6}	4.0×10^{5}	9.5×10^{5}

BACTERIA: AEROBIC	NOV 18	NOV 18	DEC 2	DEC 2	DEC 16
7°C	7.0×10^{4}	3.6×10^{5}	1.8×10^{5}	1.5×10^{5}	8.0×10^{4}
20°C	1.5×10^{5}	4.0×10^{5}	2.9×10^{5}	4.1×10^{5}	2.6×10^{5}
37°C	4.9×10^{4}	3.6×10^{4}	8.0×10^{4}	3.0×10^{4}	3.5×10^{4}
ANAEROBIC 37°C	2.5×10^{4}	4.9×10^{4}	3.0×10^{4}	2.8×10^{4}	7.7×10^{3}
COLIFORMS:	2.4×10^{3}	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$
ALGAE:	1.1×10^{6}	1.2×10^{6}	1.8×10^{6}	1.6×10^{6}	2.8×10^{6}

(continued)

TABLE I

HOLDEN
TOP SAMPLE

BACTERIA: AEROBIC	1959 JAN 6	FEB 3	MAR 10	MAY 27	MAY 27	SEPT 1
$7^{\circ}C$	1.5×10^{6}	2.4×10^{5}	2.9×10^{6}	$>3.0\times10^{6}$	$>3.0\times10^{6}$	6.2×10^{4}
$20^{\circ}C$	2.6×10^{6}	1.6×10^{5}	3.0×10^{5}	$>3.0\times10^{6}$	$>3.0\times10^{6}$	7.6×10^{4}
$37^{\circ}C$	7.4×10^{5}	3.0×10^{4}	3.5×10^{5}	2.4×10^{6}	2.6×10^{6}	$>3.0\times10^{4}$
ANAEROBIC $37^{\circ}C$	5.0×10^{5}	2.4×10^{5}	3.9×10^{5}	8.7×10^{4}	8.7×10^{4}	2.0×10^{2}
COLIFORMS:	5.4×10^{3}	5.4×10^{3}	1.6×10^{4}	$>2.4\times10^{3}$	$>2.4\times10^{3}$	1.6×10^{3}
ALGAE:	2.5×10^{5}	$>8.9\times10^{6}$	*	7.8×10^{6}	3.5×10^{6}	2.5×10^{6}

BACTERIA: AEROBIC	1960 JAN 6
$7^{\circ}C$	3.0×10^{5}
$20^{\circ}C$	2.6×10^{5}
$37^{\circ}C$	3.0×10^{4}
ANAEROBIC $37^{\circ}C$	2.3×10^{4}
COLIFORMS:	4.9×10^{3}
ALGAE:	1.9×10^{6}

* Too few Algae for an accurate count.

MICROBIAL POPULATIONS OF THE HOLDEN SEWAGE LAGOON

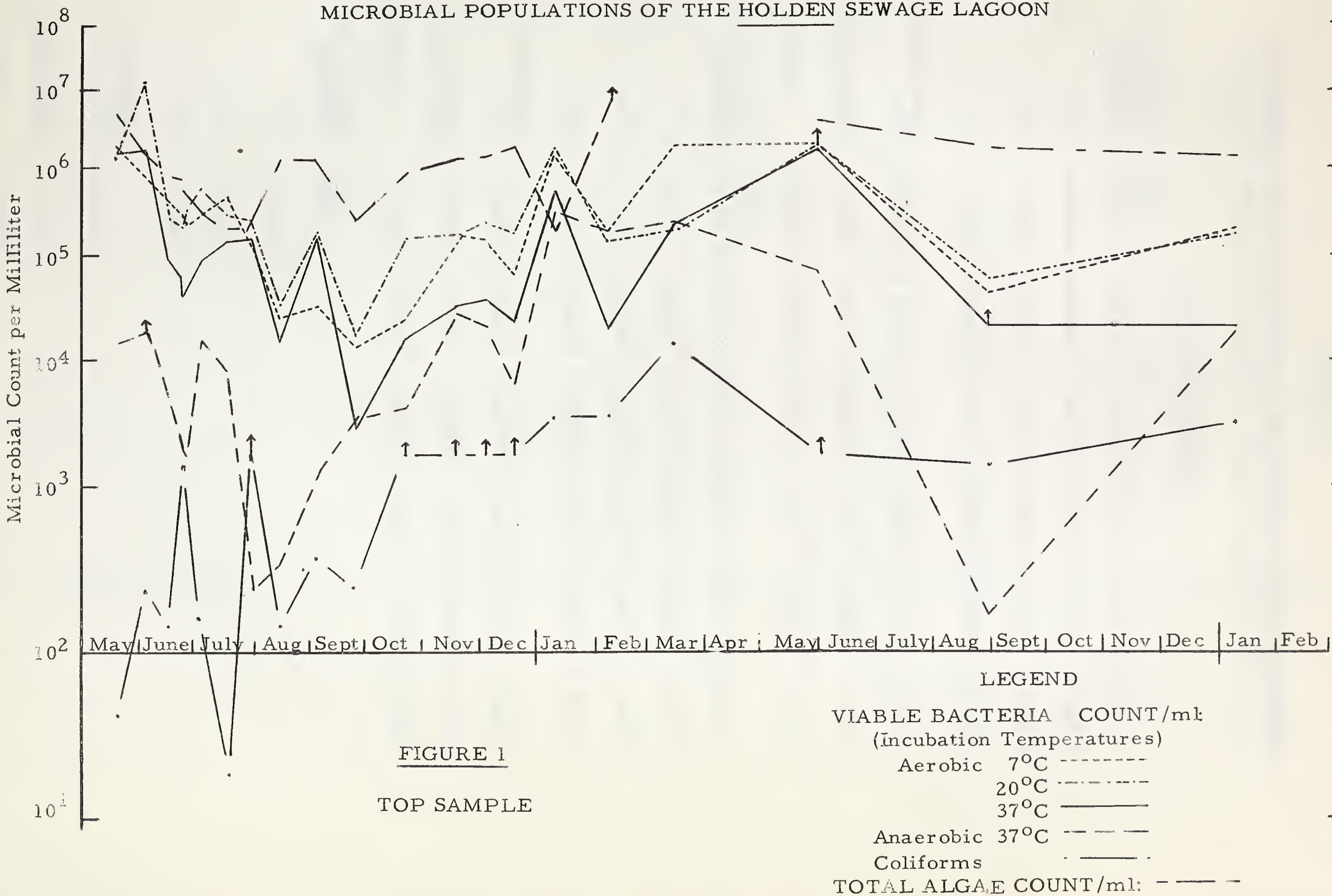

FIGURE 1

TOP SAMPLE

TABLE II

MICROBIAL POPULATIONS IN THE HOLDEN SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

BOTTOM SAMPLE

BACTERIA:	1958					
AEROBIC	JUNE 4	JUNE 17	JUNE 24	JUNE 25	JUNE 25	JULY 4
7°C	unknown	unknown	$5.6x10^5$	$4.3x10^5$	$3.9x10^5$	$5.0x10^5$
20°C	$9.3x10^6$	$3.2x10^5$	$4.5x10^5$	$5.4x10^5$	$4.1x10^5$	$7.0x10^5$
37°C	$1.0x10^6$	$6.9x10^4$	$8.9x10^4$	$8.2x10^4$	$6.4x10^4$	$9.0x10^4$
ANAEROBIC 37°C	$>3.0x10^4$	$4.2x10^3$	$7.4x10^3$	$1.2x10^4$	$1.6x10^4$	$1.2x10^4$
COLIFORMS:	$3.5x10^2$	$2.4x10^2$	$>2.4x10^3$	$9.2x10^2$	$3.5x10^2$	$1.7x10^2$
ALGAE:	unknown	unknown	$2.0x10^5$	$9.6x10^5$	$5.5x10^5$	$4.5x10^5$

BACTERIA:	1958					
AEROBIC	JULY 18	JULY 30	AUG 15	SEPT 4	SEPT 24	OCT 21
7°C	$3.7x11^5$	$2.0x10^5$	$6.9x10^4$	$4.5x10^4$	$2.4x10^4$	$3.0x10^4$
20°C	$4.1x10^5$	$3.2x10^5$	$6.6x10^4$	$4.6x10^4$	$2.3x10^4$	$1.4x10^5$
37°C	$1.9x10^5$	$2.4x10^5$	$1.3x10^4$	$3.6x10^4$	$4.0x10^3$	$2.0x10^4$
ANAEROBIC 37°C	$1.6x10^4$	$8.0x10^2$	$6.0x10^2$	$9.5x10^2$	$3.0x10^3$	$2.0x10^4$
COLIFORMS:	$2.4x10^1$	$2.4x10^2$	$1.3x10^2$	$1.6x10^3$	$5.4x10^2$	$>2.4x10^3$
ALGAE:	$2.0x10^5$	$7.5x10^4$	$1.1x10^6$	$1.9x10^6$	$5.0x10^5$	$1.5x10^6$

BACTERIA:	1959
AEROBIC	SEPT 1
7°C	$2.3x10^5$
20°C	$1.6x10^5$
37°C	$1.0x10^4$
ANAEROBIC 37°C	$2.2x10^3$
COLIFORMS:	$5.4x10^2$
ALGAE:	$3.6x10^6$

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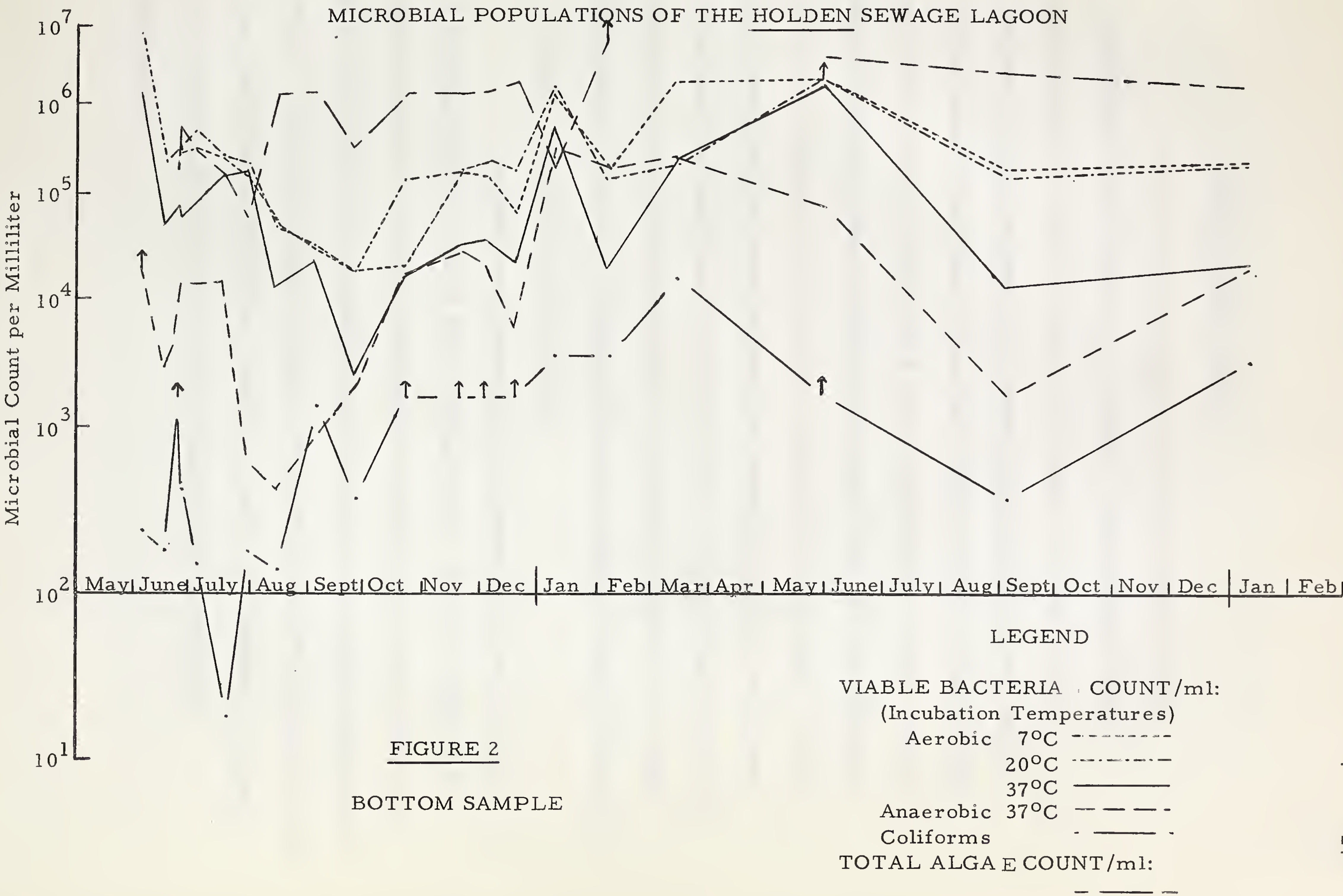


FIGURE 2

BOTTOM SAMPLE

Holden Sewage Lagoon

The detention time for the storage lagoon at Holden is calculated to be 274 days, i.e., the time required to fill to the maximum possible depth of 4 feet. The lagoon is not used to its maximum capacity because it is drained to the one foot level in April and November of each year. Since only 3 feet of depth is actually used, the detention time is really 205.5 days. (Appendix B). There are two periods when the lagoon is filling with sewage fluid, one from April to November through the warm seasons when there is open water, and the other throughout the winter season from November to April when most of the water is transformed into the ice cover. The thickness of the ice increases throughout the winter (from 0 inches to 24 inches) and varies from winter to winter. The liquid portion also varies in depth (January/59 - 6 inches; January/60 - 16 inches).

Samples were taken from the lagoon during the 20 month period June 4/58 to January 6/60. (Appendix A). When the depth of the liquid became too shallow, following the draining of the lagoon to the one foot level, or after the formation of the ice cover, only single samples were taken. Both top and bottom samples were taken in the summertime when the liquid increased in depth from 2 feet to 3.3 feet. The samples were taken at a location in the body of the lagoon 40 feet from the west bank. (Appendix C).

The environmental factors were determined throughout the investigation. (Table X1X). The dissolved oxygen was measured by the Winkler method. During the warm months the concentration was quite variable. The highest concentration 18.8 ppm of dissolved oxygen occurred in July/58. In November/58 after 4 inches of ice formed over 8 inches of liquid and the lagoon temperature was 0.75°C there was 9.7 ppm of dissolved oxygen present. During the winter subsequent samples contained no measurable dissolved oxygen. The temperature of the sewage fluid at the time of sampling was the same for both the top and bottom samples. The maximum temperature measured was 25°C which occurred in July/58. The minimum temperature, 1° - 0°C occurred during the winter from November/58 to February/59. The range of pH varied between 9.6 in July/58 and 7.6 in March/59., thus the sewage fluid was always alkaline at the time of sampling. However, it was more alkaline during the warmer months.

The aerobic viable bacteria counts at the incubation temperatures of 7°, 20°, and 37.5°C followed the same general yearly pattern of fluctuation. (Tables 1, 11; Figures 1, 2, 10 - 20). This pattern appeared to follow the draining and the filling routine of the fluid volume of the lagoon. Following the drainage of the lagoon to the one foot depth of liquid in April/58 the counts were at their highest. After the sewage filled the lagoon to the depth of 3.3 feet in September/58, the counts were at their lowest value. During the winter period as sewage was filling the lagoon

and the liquid was being transformed into ice, the counts continued to increase to high values again. While the lagoon was being filled to a depth of 12 inches under an ice cover of 18 inches by February /59, the count of anaerobes increased by 100-fold and the aerobes decreased in count. The aerobes returned to the January /59 level by March /59. After the ice melted the lagoon was drained to the one foot level in April /59. In May /59 when a full year of investigation was completed the counts of the aerobes were again near the high counts of June /58.

From June /58 to the middle of July /58 the coliforms decreased to their lowest value near 10^1/ml. From July to March /59 near the end of the winter and under the cover of ice the coliforms increased to 10^4/ml.

The viable count of anaerobic bacteria grown at 37.5°C followed a similar fluctuation, but the minimum count came at the end of July /58 at the level of 10^2/ml. During the fall and early winter, as the lagoon was drained and filled again and as ice formed on the surface, there was a steady increase in count to 10^5/ml. by January /59. The count remained high and steady until May /59. At this time the count was again similar to June /58.

The general trends shown in aerobic, anaerobic and coliform counts from June /58 to May /59 were repeated the following year.

The algae maintained a high count of 10^5 to 10^6/ml throughout the investigation except when they were too numerous to count (February /59) or not evident (March /59) in the sample.

During the summer of 1958 from June to September the crustacean, daphnia, and the protozoan, paramecium, were present.

TABLE III

MICROBIAL POPULATIONS IN THE DAYSLAND SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

TOP SAMPLE

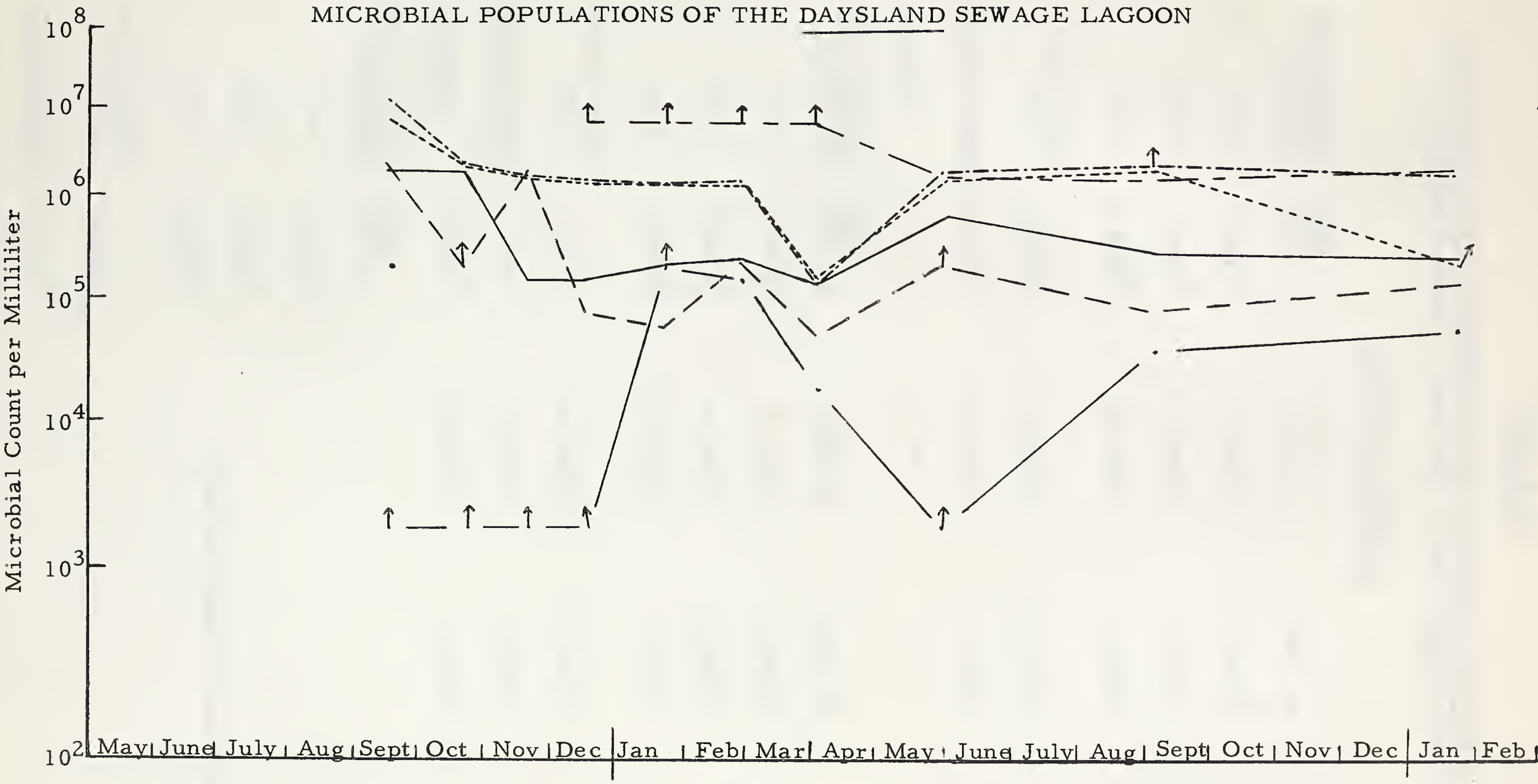
BACTERIA: AEROBIC	1958 SEPT 16	OCT 21	NOV 18	DEC 16
7°C	$8.5x10^6$	$3.1x10^6$	$1.9x10^6$	$1.2x10^6$
20°C	$1.0x10^7$	$3.6x10^6$	$2.4x10^6$	$1.6x10^6$
37°C	$2.7x10^6$	$2.4x10^6$	$1.8x10^5$	$1.6x10^5$
ANAEROBIC 37°C	$2.9x10^6$	$>3.0x10^5$	$2.9x10^6$	$8.8x10^4$
COLIFORMS:	$>2.4x10^3$	$>2.4x10^3$	$>2.4x10^3$	$>2.4x10^3$
ALGAE:	$3.0x10^5$	*	*	$>8.0x10^6$

BACTERIA: AEROBIC	1959 JAN 20	FEB 24	MAR 31	MAY 28	SEPT 1
7°C	$1.3x10^6$	$1.1x10^6$	$1.5x10^5$	$1.4x10^6$	$2.6x10^6$
20°C	$1.2x10^6$	$1.4x10^6$	$1.1x10^5$	$2.2x10^6$	$3.0x10^6$
37°C	$3.1x10^5$	$3.8x10^5$	$1.1x10^5$	$8.0x10^5$	$4.0x10^5$
ANAEROBIC 37°C	$7.3x10^4$	$3.3x10^5$	$6.8x10^4$	$> 3.0x10^5$	$8.7x10^4$
COLIFORMS:	$>2.4x10^5$	$1.6x10^5$	$2.3x10^4$	$>2.4x10^3$	$5.4x10^4$
ALGAE:	$>8.0x10^6$	$>8.0x10^6$	$>8.0x10^6$	$1.6x10^6$	$1.8x10^6$

BACTERIA: AEROBIC	1960 JAN 27
7°C	$>3.0x10^5$
20°C	$2.0x10^6$
37°C	$3.6x10^5$
ANAEROBIC 37°C	$1.5x10^5$
COLIFORMS:	$7.0x10^4$
ALGAE:	$2.6x10^6$

*Too few Algae for an accurate count.

MICROBIAL POPULATIONS OF THE DAYSLAND SEWAGE LAGOON



LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C
20°C
37°C
Anaerobic 37°C
Coliforms
TOTAL ALGAE COUNT/ml:

FIGURE 3

TOP SAMPLE

TABLE IV

MICROBIAL POPULATIONS IN THE DAYSLAND SEWAGE LAGOON
(Viable Bacteria Count /ml Total Algae Count /ml)

BOTTOM SAMPLE

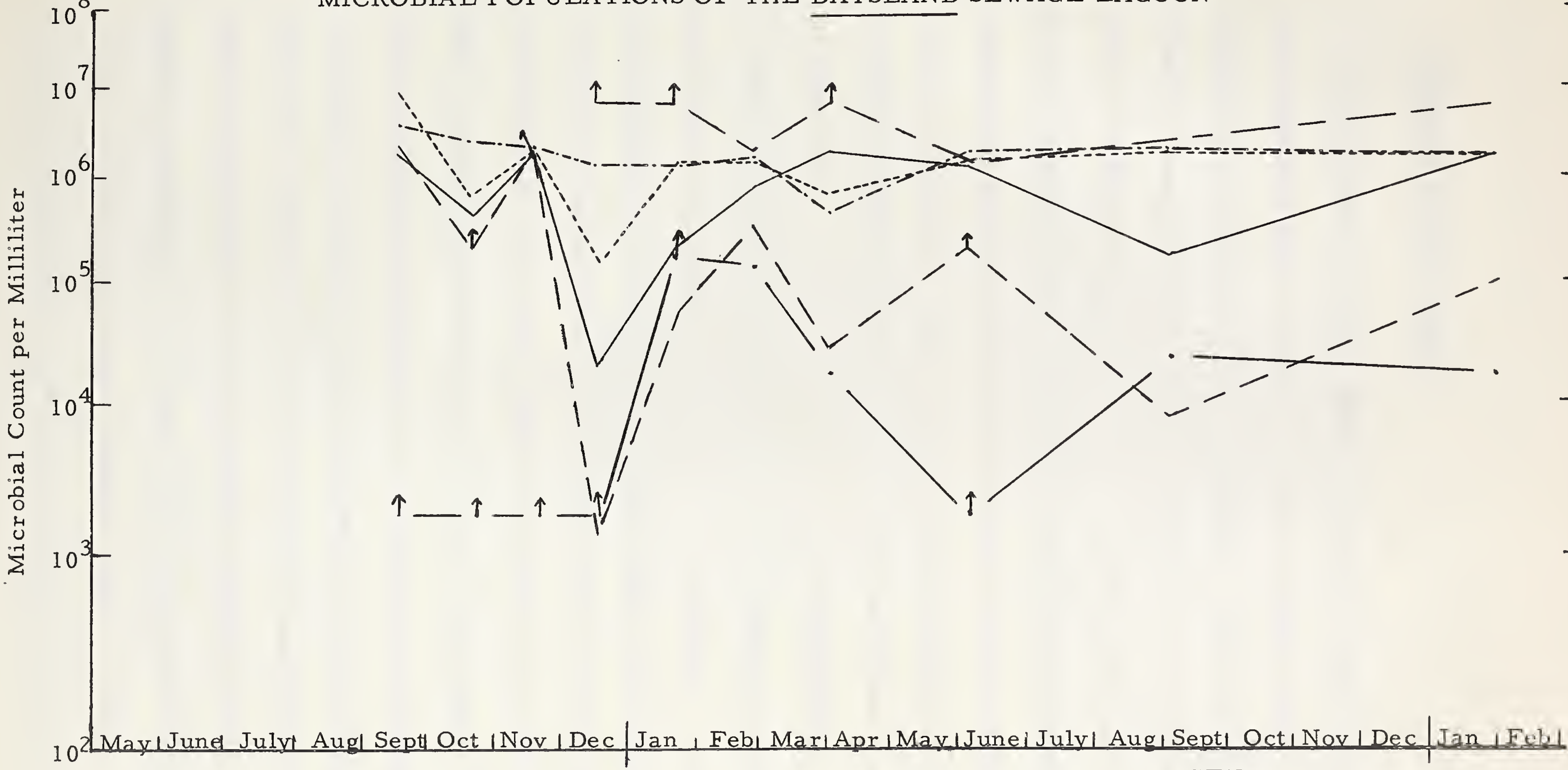
BACTERIA:	1958			
AEROBIC	SEPT 16	OCT 21	NOV 18	DEC 16
7°C	$9.6x10^6$	$7.9x10^5$	$3.0x10^6$	$1.6x10^5$
20°C	$5.6x10^6$	$3.8x10^6$	$3.2x10^6$	$1.1x10^6$
37°C	$2.4x10^6$	$6.2x10^5$	$2.9x10^6$	$2.9x10^4$
ANAEROBIC 37°C	$3.2x10^6$	$>3.0x10^5$	$>3.0x10^6$	$1.0x10^3$
COLIFORMS:	$>2.4x10^3$	$>2.4x10^3$	$>2.4x10^3$	$>2.4x10^3$
ALGAE:	*	*	*	$>8.0x10^6$

BACTERIA:	1959			
AEROBIC	FEB 24	MAR 31	MAY 28	SEPT 1
7°C	$1.7x10^6$	$8.1x10^5$	$1.9x10^6$	$2.5x10^6$
20°C	$2.0x10^6$	$6.3x10^5$	$2.6x10^6$	$3.0x10^6$
37°C	$9.0x10^5$	$2.6x10^6$	$1.1x10^6$	$2.2x10^5$
ANAEROBIC 37°C	$5.0x10^5$	$4.3x10^4$	$>3.0x10^5$	$9.0x10^3$
COLIFORMS:	$1.3x10^5$	$2.3x10^4$	$>2.4x10^3$	$3.5x10^4$
ALGAE:	$2.7x10^6$	$>8.0x10^6$	$1.6x10^6$	$3.6x10^6$

BACTERIA:	1960
AEROBIC	JAN 27
7°C	$2.3x10^6$
20°C	$2.4x10^6$
37°C	$2.2x10^6$
ANAEROBIC 37°C	$9.8x10^4$
COLIFORMS:	$2.3x10^4$
ALGAE:	$8.0x10^6$

* Too few Algae for an accurate count.

MICROBIAL POPULATIONS OF THE DAYSLAND SEWAGE LAGOON



LEGEND

VIABLE BACTERIA COUNT/ml:

(Incubation Temperatures)

Aerobic 7°C

20°C

37°C

Anaerobic 37°C

Coliforms

TOTAL ALGAE COUNT/ml:

FIGURE 4

BOTTOM SAMPLE

Daysland Sewage Lagoon.

A short detention lagoon which takes only 6.2 days to fill to its maximum depth of 6 feet is used as a sludge pit for the raw sewage received from the town of Daysland. After the lagoon is filled the sewage liquid overflows continuously into a slough. Sludge is filling the lagoon at a rate of 12 inches per year, decreasing the detention time. The maximum depth at the beginning of the sampling period in September /58 was 46 inches and the actual detention time was 4.1 days. When the final sample was taken in January /60 the depth was only 30 inches and the overflow occurred after 2.6 days of filling the lagoon (Appendix B).

During the winter the temperature in this lagoon is maintained at a higher level and thus only a thin ice cover forms. In January /59 the temperature was 3°C when the liquid depth was 42 inches and the ice was 9 inches thick. By February /59 the ice was only 12 inches thick. In January /60 the temperature was 1.5°C, the depth 30 inches and the ice cover was only 7 inches thick. No dissolved oxygen was detected by the Winkler method throughout the investigation. Only one sample in September /59 had an acid reaction (pH 6.95); all others were alkaline within the range of pH 7.9 to 7.25. Both the top and bottom samples had the same temperature. The maximum temperature recorded, 15.5°C, occurred in September /58 and the minimum temperature during the winter of 1958 was 3°C. (The lowest temperature, 1.5°C, was in January /60 when the

liquid was 30 inches deep). (Table xx)

Samples were taken from the lagoon during the 17 month period from September 16/58 to January 27/60 (Appendix A). The samples were taken from the body of the lagoon in the northwest corner (Appendix C). The samples were taken between noon and 2:30 p.m. They were taken once a month from September /58 to March /59; then again in May and September of 1959 and finally in January 1960.

The microbial counts were nearly constant and remained high with minimal fluctuations throughout all the seasons. (Tables III, IV; Figures 3, 4, 10-20)

Aerobic bacteria grown at 7°C and 20°C maintained a high count slightly above 10^6/ml. throughout the investigation. The aerobes grown at 37.5°C were at a slightly lower count during the same period. From September /58 to January /59 the count decreased from 10^6 to near 10^5/ml. and maintained a steady count until January /60 though the plate count fluctuated slightly. The coliform count was never less than approximately 10^4/ml. Through the fall of 1958 the Most Probable Number was probably greater than 10^5/ml. (the count of the February /59 sample). Then the coliform count decreased to between 10^5 and 10^4/ml. and maintained a steady count greater than 10^4/ml. until January /60. From September /58 until the ice formed in November the anaerobic count was at 10^6/ml. From December /58 to January /60 the count fluctuated about 10^5/ml. The total algae count was low in September /58 (10^5/ml). In October /58 during the open water and then

in November /58 when the ice had formed there were too few algae to count accurately. During the period from December /58 to February /59 when there was an ice cover and the liquid averaged a temperature of $3^{\circ}C$ and in March /59 when there was open water and a temperature of $5^{\circ}C$ the algae were too numerous to count (greater than 8.0×10^{6}/ml) and the odor was that of a pig pen. From May /59 until January /60 the total algae count averaged 10^{6}/ml and the normal sewage odor was present. (Appendix E)

TABLE V

MICROBIAL POPULATIONS IN THE BRUDERHEIM SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

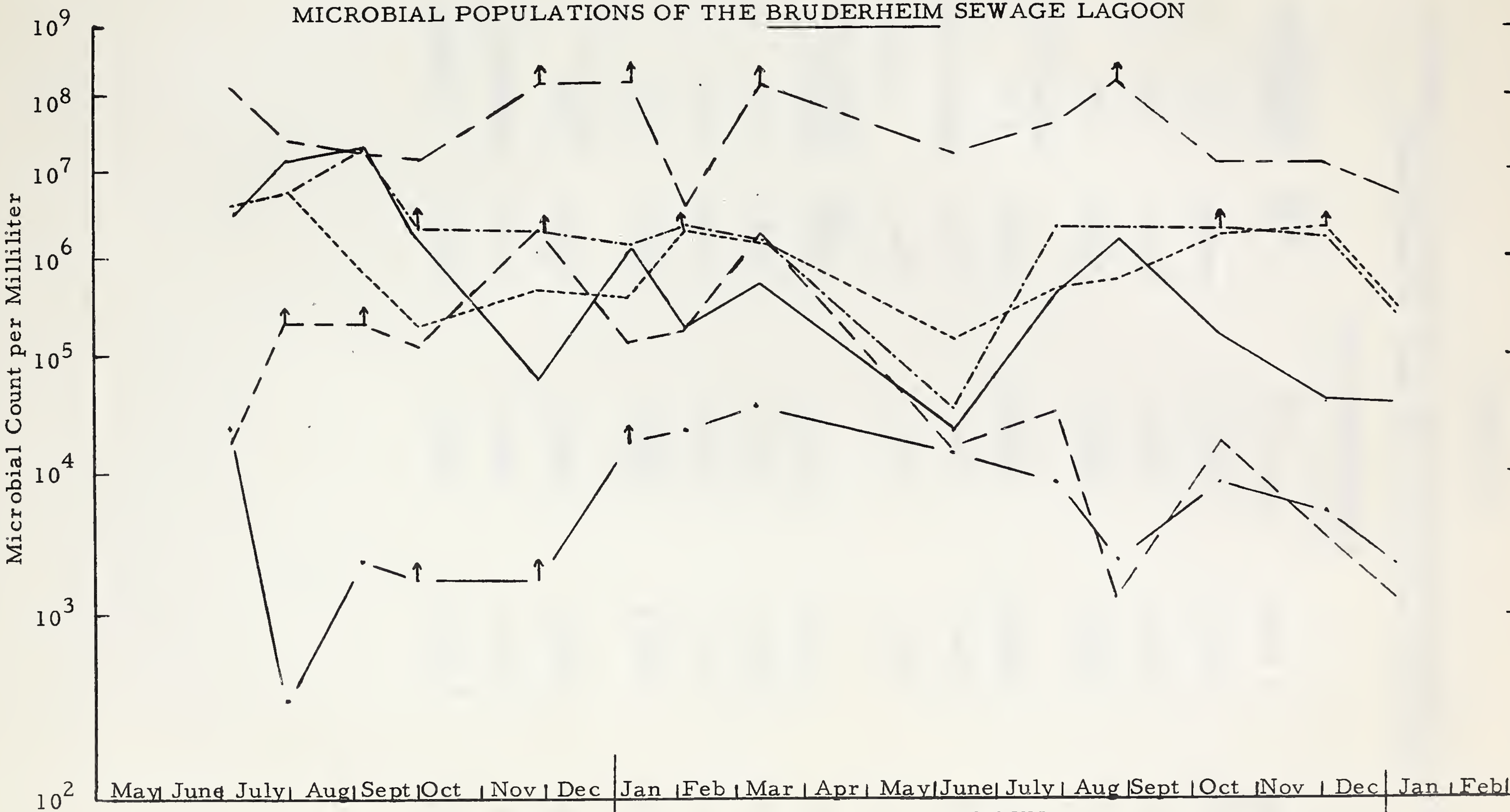
TOP SAMPLE

BACTERIA:	1958					
AEROBIC	JULY 3	JULY 30	SEPT 4	SEPT 30	NOV 26	NOV 26
7°C	unknown	7.7×10^{6}	1.1×10^{6}	6.1×10^{5}	5.9×10^{5}	8.1×10^{5}
20°C	4.7×10^{6}	7.4×10^{6}	2.9×10^{7}	$>3.0\times10^{6}$	2.9×10^{6}	$>3.0\times10^{6}$
37°C	3.2×10^{6}	1.3×10^{7}	3.7×10^{7}	2.0×10^{6}	8.0×10^{4}	8.0×10^{4}
ANAEROBIC 37°C	2.6×10^{4}	$>3.0\times10^{5}$	$>3.0\times10^{5}$	9.0×10^{4}	3.0×10^{6}	3.0×10^{6}
COLIFORMS:	5.4×10^{4}	4.8×10^{2}	5.4×10^{3}	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$
ALGAE:	1.3×10^{8}	3.9×10^{7}	1.7×10^{7}	1.3×10^{7}	1.6×10^{8}	$>1.6\times10^{8}$

BACTERIA:	1959					
AEROBIC	JAN 8	FEB 3	MAR 10	JUNE 10	JULY 29	AUG 27
7°C	5.7×10^{5}	$>3.0\times10^{6}$	1.2×10^{6}	1.5×10^{5}	6.3×10^{5}	7.5×10^{5}
20°C	1.2×10^{6}	3.8×10^{6}	1.7×10^{6}	5.2×10^{4}	3.0×10^{6}	3.0×10^{6}
37°C	1.0×10^{6}	2.8×10^{5}	7.2×10^{5}	3.4×10^{4}	6.0×10^{5}	2.0×10^{6}
ANAEROBIC 37°C	1.1×10^{5}	2.6×10^{5}	2.2×10^{6}	2.0×10^{4}	5.0×10^{4}	1.1×10^{3}
COLIFORMS:	$>2.4\times10^{4}$	3.5×10^{4}	5.4×10^{4}	1.6×10^{4}	9.2×10^{3}	3.3×10^{3}
ALGAE:	$>1.6\times10^{8}$	5.4×10^{6}	$>1.6\times10^{8}$	2.2×10^{7}	6.2×10^{7}	$>1.6\times10^{8}$

BACTERIA:	1959			1960	
AEROBIC	OCT 14	DEC 2	DEC 2	JAN 5	JAN 5
7°C	2.2×10^{6}	$>3.0\times10^{6}$	1.7×10^{6}	4.5×10^{5}	2.3×10^{5}
20°C	$>3.0\times10^{6}$	2.0×10^{6}	1.8×10^{6}	3.7×10^{5}	3.5×10^{5}
37°C	1.8×10^{5}	5.4×10^{4}	6.3×10^{4}	5.6×10^{4}	7.0×10^{4}
ANAEROBIC 37°C	2.2×10^{4}	6.5×10^{3}	3.2×10^{3}	1.2×10^{3}	1.5×10^{4}
COLIFORMS:	9.2×10^{3}	6.4×10^{3}	7.9×10^{3}	3.3×10^{3}	3.3×10^{3}
ALGAE:	1.0×10^{7}	8.5×10^{6}	1.5×10^{7}	7.1×10^{6}	8.4×10^{6}

MICROBIAL POPULATIONS OF THE BRUDERHEIM SEWAGE LAGOON



LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C
20°C
37°C
Anaerobic 37°C
Coliforms

TOTAL ALGAE COUNT/ml:

FIGURE 5

TOP SAMPLE

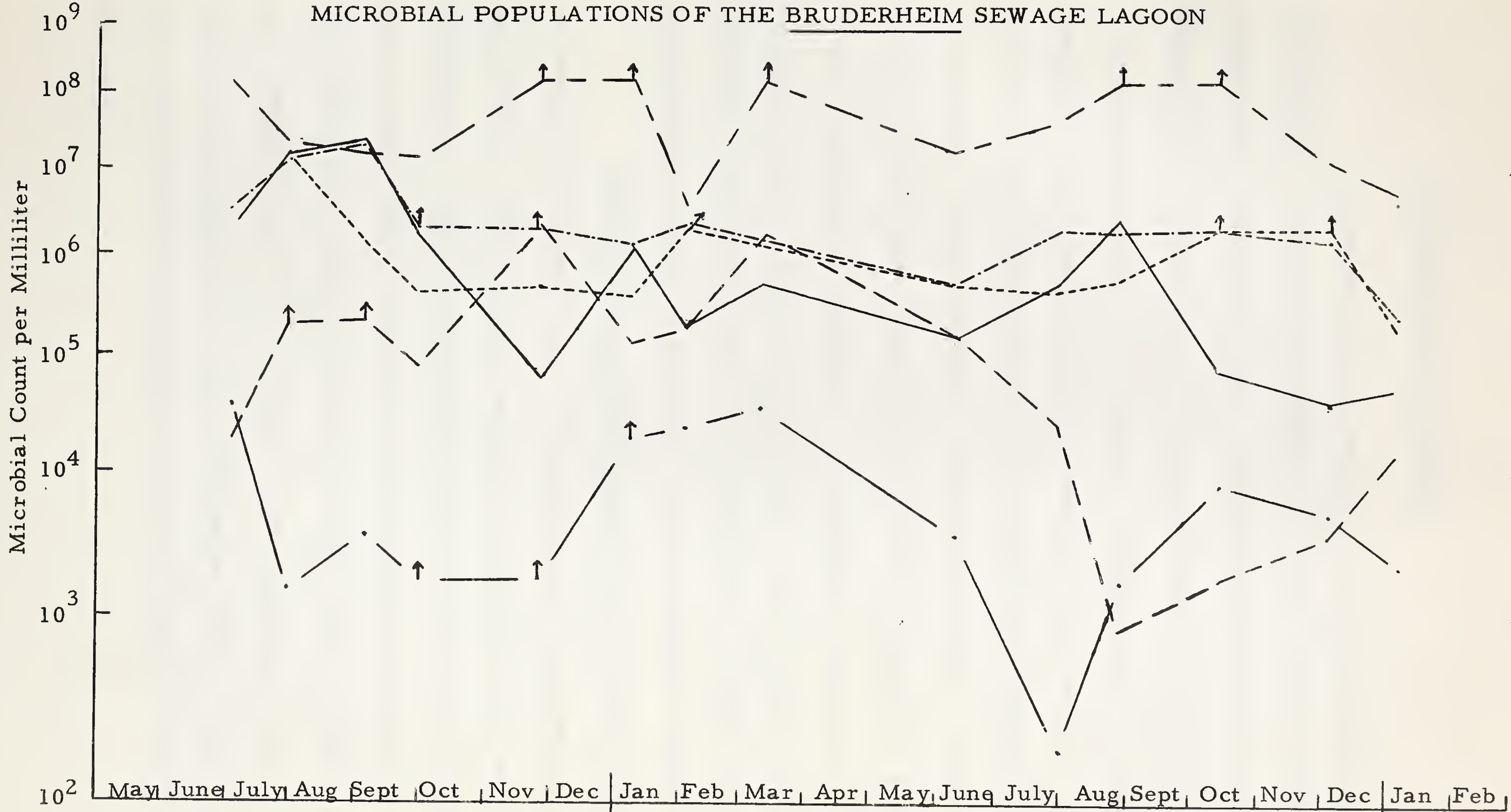
TABLE VI

MICROBIAL POPULATIONS IN THE BRUDERHEIM SEWAGE LAGOON
(Viable Bacteria Count /ml Total Algae Count /ml)

BOTTOM SAMPLE

BACTERIA:	1958			
AEROBIC	JULY 3	JULY 30	SEPT 4	SEPT 30
7°C	unknown	1.1×10^7	8.6×10^5	3.0×10^5
20°C	5.5×10^6	1.2×10^7	2.9×10^7	$>3.0 \times 10^6$
37°C	4.4×10^6	1.7×10^7	3.2×10^7	2.0×10^6
ANAEROBIC 37°C	2.2×10^4	$>3.0 \times 10^5$	$>3.0 \times 10^5$	1.0×10^5
COLIFORMS:	3.5×10^4	1.7×10^3	3.5×10^3	$>2.4 \times 10^3$
ALGAE:	1.0×10^8	3.2×10^7	2.3×10^7	1.5×10^7
BACTERIA:	1959			
AEROBIC	JUNE 10	JULY 29	AUG 27	OCT 14
7°C	6.8×10^5	6.2×10^5	7.3×10^5	$>3.0 \times 10^6$
20°C	6.9×10^5	2.7×10^6	2.7×10^6	$>3.0 \times 10^6$
37°C	1.6×10^5	7.0×10^5	4.2×10^6	8.6×10^4
ANAEROBIC 37°C	2.0×10^5	3.8×10^4	9.2×10^2	2.5×10^3
COLIFORMS:	5.4×10^3	2.6×10^2	2.4×10^3	9.2×10^3
ALGAE:	2.2×10^7	6.5×10^7	$>1.6 \times 10^8$	$>1.6 \times 10^8$

MICROBIAL POPULATIONS OF THE BRUDERHEIM SEWAGE LAGOON



LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C - - - - - - - -
20°C -·-·-·-·-
37°C ————
Anaerobic 37°C — — — —
Coliforms · —— ·

TOTAL ALGAE COUNT/ml:
— —— —

FIGURE 6

BOTTOM SAMPLE

Bruderheim Sewage Lagoon

During the summer and winter of 1958 the Bruderheim lagoon was used as a storage lagoon and during the warm season of 1959 as a continuously overflowing lagoon. The calculated detention time is 200 days to fill the lagoon to the maximum possible depth of 4 feet. The actual storage time of this lagoon is 150 days when the lagoon is drained to the one foot level and only the top 3 feet are used. (Appendix B) In the first warm season the lagoon was filled to the depth of approximately 3.5 feet from April to November /58 and then drained. During the winter of 1958 the lagoon was used to store the sewage fluid, allowed to fill to the maximum capacity of 4 feet and then allowed to overflow during the following warm season of 1959. The overflow continued until November /59 when the lagoon was drained to the one foot level. During the final winter the lagoon was again filling as a storage lagoon.

Sampling occurred over a period of 19 months from July 3/58 to January 5/60 (Appendix A). The samples were taken between 11:00 A.M. and 3:00 P.M. from the outlet location at the middle of the north bank (Appendix C). The use of the lagoon from June /58 to June /59 could have been considered as a full year of routine operation except that the lagoon was allowed to overflow during the open water season of 1959. However, a full sampling year with a standard routine of operation occurred between the time of drainage of the lagoon in November /58 and in November /59. The study from the microbiological point of view will be considered during this time.

The environmental factors before November /58 were not considered since they were incomplete up to this date. After November /58 the environmental factors were as follows: No measurable dissolved oxygen was evident in any of the samples. The maximum temperature recorded in the lagoon was 20^{o}C in July /59. The minimum temperature observed was 0.25^{o}C in November /58. The pH was alkaline during the warm seasons, fluctuating about 7.7, while under the ice the pH was 7.0 and as low as 5.95. (Table XXII)

Only single samples were taken during the winter storage period of 1958. As the sewage liquid filled the lagoon an ice cover formed probably beginning at the time of the November /58 sample. The ice increased in depth to 3.5 feet by March /59. The liquid remained at the one foot level and then decreased to 0.5 feet in March /59. The liquid was acidic, had a pigpen odor and was at a temperature of 0.5^{o}C during this period.

During this storage period the 20^{o}C aerobes maintained a count slightly greated than the 10^{6}/ml. level and the 7^{o}C aerobes fluctuated about 10^{6}/ml. (Tables V, VI; Figures 5, 6, 10-20). The 37.5^{o}C aerobes fluctuated within the 10^{6} to 10^{5}/ml. range. The anaerobes which were at 10^{6}/ml. in November /58 decreased to 10^{5}/ml. during January and February /59 and then returned to 10^{6}/ml. in March /59. The Most Probable Number of coliforms was near to 5.0 x 10^{4}/ml. throughout the winter. The algae were too numerous to count (greater

[illegible]

than 1.6 x 10^6/ml.). From November /58 to March /59, though the count decreased to 10^6/ml. in February /59. (Appendix E)

Four samples were taken during the period of overflow in the open water season. Both top and bottom samples were taken at the outlet region. The period ended with drainage of the lagoon to the one foot level in November /59.

All the microbial counts were decreasing when the June /59 sample was taken. On this date the aerobes reached the lowest count of the open water period. The 7°C aerobes decreased to slightly above 10^5/ml. and then increased to 10^6/ml. level by October /59. After fluctuating to a count slightly greater than 10^5/ml. the 20°C aerobes returned to a steady count of approximately 3.0 x 10^6/ml. until October /59. The 37.5°C aerobes fluctuated from 10^4/ml. in June /59 to 10^6/ml. in August /59 and then decreased to slightly above 10^5/ml. in October /59. The anaerobes continued to decrease to a minimum count of 10^3/ml. in August /59 and by October /59 the count had increased to slightly above 10^6/ml. In August /59 the Most Probable Number of coliforms reached the lowest count (near 10^3/ml.) and then increased towards 10^4/ml. by October /59. The total count of algae fluctuated near 10^7/ml. in June and July /59 and then became too numerous to count by August and October /59.

During the winter of 1959-60, which was milder than the previous winter, the sewage liquid filled to a greater depth (2 feet) than in February /59 (1 foot) and the ice was only 1.5 feet by January /60 as compared to 3 feet in February /59. By January /60

most microbial counts were lower than in January /59. The aerobes incubated at $7^{o}C$ and $20^{o}C$ were between 10^5 and 10^6/ml. The 37.5^{o} aerobes, anaerobes and coliforms were lower than the previous January counts by one-tenth. The total algae count was near 10^7/ml. by January /60.

TABLE VII

MICROBIAL POPULATIONS IN THE LACOMBE SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

TOP SAMPLE

BACTERIA:	1958					
AEROBIC	JULY 17	JULY 24	JULY 31	AUG 7	AUG 27	SEPT 10
7°C	2.4×10^{5}	2.0×10^{5}	4.1×10^{5}	1.7×10^{5}	1.2×10^{5}	4.6×10^{5}
20°C	4.2×10^{5}	5.5×10^{5}	7.0×10^{5}	2.5×10^{5}	2.6×10^{5}	6.9×10^{5}
37°C	8.7×10^{4}	1.0×10^{5}	3.2×10^{5}	1.4×10^{5}	3.5×10^{5}	4.0×10^{5}
ANAEROBIC 37°C	1.4×10^{2}	$>3.0\times10^{5}$	6.5×10^{2}	1.0×10^{4}	9.0×10^{3}	1.6×10^{4}
COLIFORMS:	6.8×10^{2}	2.2×10^{2}	3.5×10^{2}	3.5×10^{2}	$>2.4\times10^{3}$	$>2.4\times10^{3}$
ALGAE:	3.0×10^{5}	4.5×10^{5}	1.5×10^{6}	6.0×10^{5}	6.5×10^{5}	6.5×10^{5}

BACTERIA:	1958					
AEROBIC	SEPT 16	OCT 14	NOV 25	NOV 25	DEC 9	DEC 30
7°C	8.7×10^{5}	1.2×10^{6}	7.8×10^{5}	6.3×10^{5}	2.0×10^{6}	1.1×10^{6}
20°C	1.3×10^{6}	9.6×10^{5}	7.4×10^{5}	7.4×10^{5}	3.0×10^{6}	2.1×10^{6}
37°C	1.2×10^{6}	5.9×10^{5}	3.4×10^{5}	3.4×10^{5}	2.8×10^{6}	3.8×10^{5}
ANAEROBIC 37°C	2.2×10^{4}	1.4×10^{5}	$>3.0\times10^{4}$	1.5×10^{5}	$>3.0\times10^{5}$	3.9×10^{5}
COLIFORMS:	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{3}$	$>2.4\times10^{4}$
ALGAE:	5.0×10^{5}	1.1×10^{6}	6.0×10^{5}	*	1.3×10^{6}	1.0×10^{5}

BACTERIA:	1959						1960
AEROBIC	JAN 14	FEB 17	MAR 24	JUNE 3	JULY 8	SEPT 1	JAN 13
7°C	2.1×10^{5}	6.2×10^{5}	7.4×10^{5}	2.3×10^{6}	1.1×10^{6}	1.3×10^{5}	3.2×10^{5}
20°C	5.4×10^{5}	1.1×10^{6}	6.9×10^{5}	3.9×10^{6}	1.1×10^{6}	3.0×10^{5}	7.7×10^{5}
37°C	9.5×10^{4}	4.2×10^{5}	3.3×10^{5}	2.8×10^{6}	8.7×10^{4}	2.8×10^{4}	1.5×10^{5}
ANAEROBIC 37°C	2.2×10^{4}	3.0×10^{5}	2.7×10^{5}	3.9×10^{4}	6.0×10^{3}	3.0×10^{3}	8.3×10^{4}
COLIFORMS:	5.4×10^{4}	5.4×10^{4}	3.5×10^{4}	3.5×10^{3}	$>2.4\times10^{4}$	5.4×10^{2}	3.5×10^{4}
ALGAE:	$>1.9\times10^{6}$	unknown	1.5×10^{6}	3.5×10^{5}	7.5×10^{5}	2.6×10^{5}	6.5×10^{5}

* Too few Algae for an accurate count.

MICROBIAL POPULATIONS OF THE LACOMBE SEWAGE LAGOON

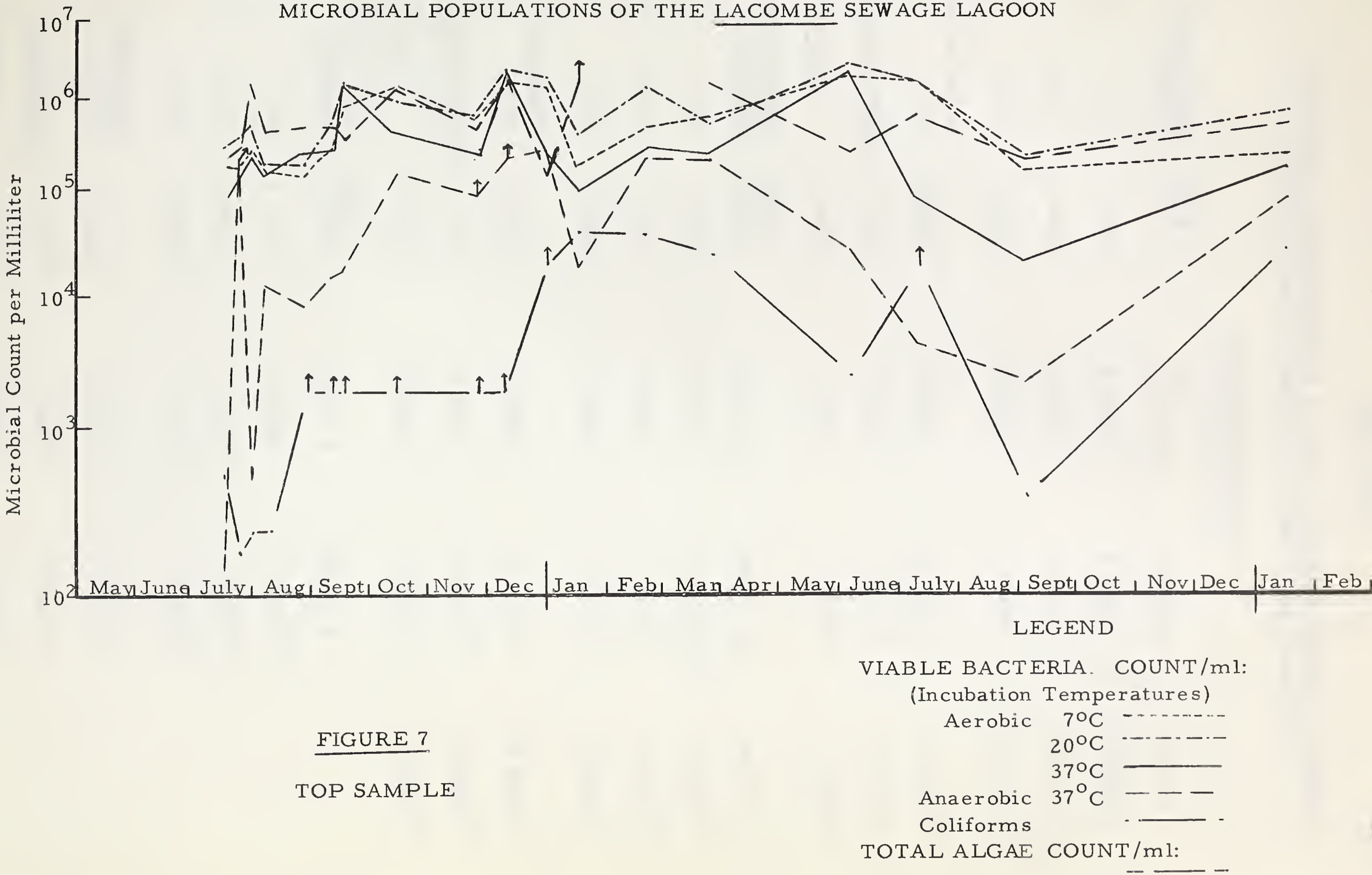


FIGURE 7

TOP SAMPLE

TABLE VIII

MICROBIAL POPULATIONS IN THE LACOMBE SEWAGE LAGOON
(Viable Bacteria Count /ml Total Algae Count /ml)

BOTTOM SAMPLE

BACTERIA: AEROBIC	1958 JULY 17	JULY 24	JULY 31	AUG 7
7°C	2.3×10^5	4.6×10^5	2.9×10^5	2.2×10^5
20°C	2.8×10^5	6.0×10^5	6.5×10^5	3.6×10^5
37°C	7.8×10^4	1.6×10^5	1.6×10^5	2.2×10^5
ANAEROBIC 37°C	1.8×10^2	$>3.0 \times 10^5$	9.0×10^2	1.2×10^4
COLIFORMS:	1.1×10^3	1.7×10^2	2.2×10^2	9.2×10^2
ALGAE:	1.0×10^5	1.9×10^6	1.1×10^6	1.1×10^6

BACTERIA: AEROBIC	1958 AUG 27	SEPT 10	SEPT 16	OCT 14
7°C	1.1×10^5	6.5×10^5	7.4×10^5	9.5×10^5
20°C	2.5×10^5	7.1×10^5	1.1×10^6	2.1×10^6
37°C	6.5×10^5	4.8×10^5	1.2×10^6	3.8×10^5
ANAEROBIC 37°C	1.8×10^4	1.2×10^4	2.1×10^4	$>3.0 \times 10^5$
COLIFORMS:	$>2.4 \times 10^3$	$>2.4 \times 10^3$	$>2.4 \times 10^3$	$>2.4 \times 10^3$
ALGAE:	8.0×10^5	4.5×10^5	3.5×10^5	1.3×10^6

BACTERIA: AEROBIC	1959 JUNE 3	JULY 8	SEPT 1
7°C	2.1×10^6	5.7×10^5	5.2×10^5
20°C	3.9×10^6	7.0×10^5	4.3×10^5
37°C	2.9×10^6	1.1×10^5	2.0×10^5
ANAEROBIC 37°C	2.0×10^4	4.2×10^3	2.2×10^3
COLIFORMS:	1.7×10^3	1.6×10^4	$>2.4 \times 10^3$
ALGAE:	1.4×10^6	2.7×10^5	1.1×10^5

MICROBIAL POPULATIONS OF THE LACOMBE SEWAGE LAGOON

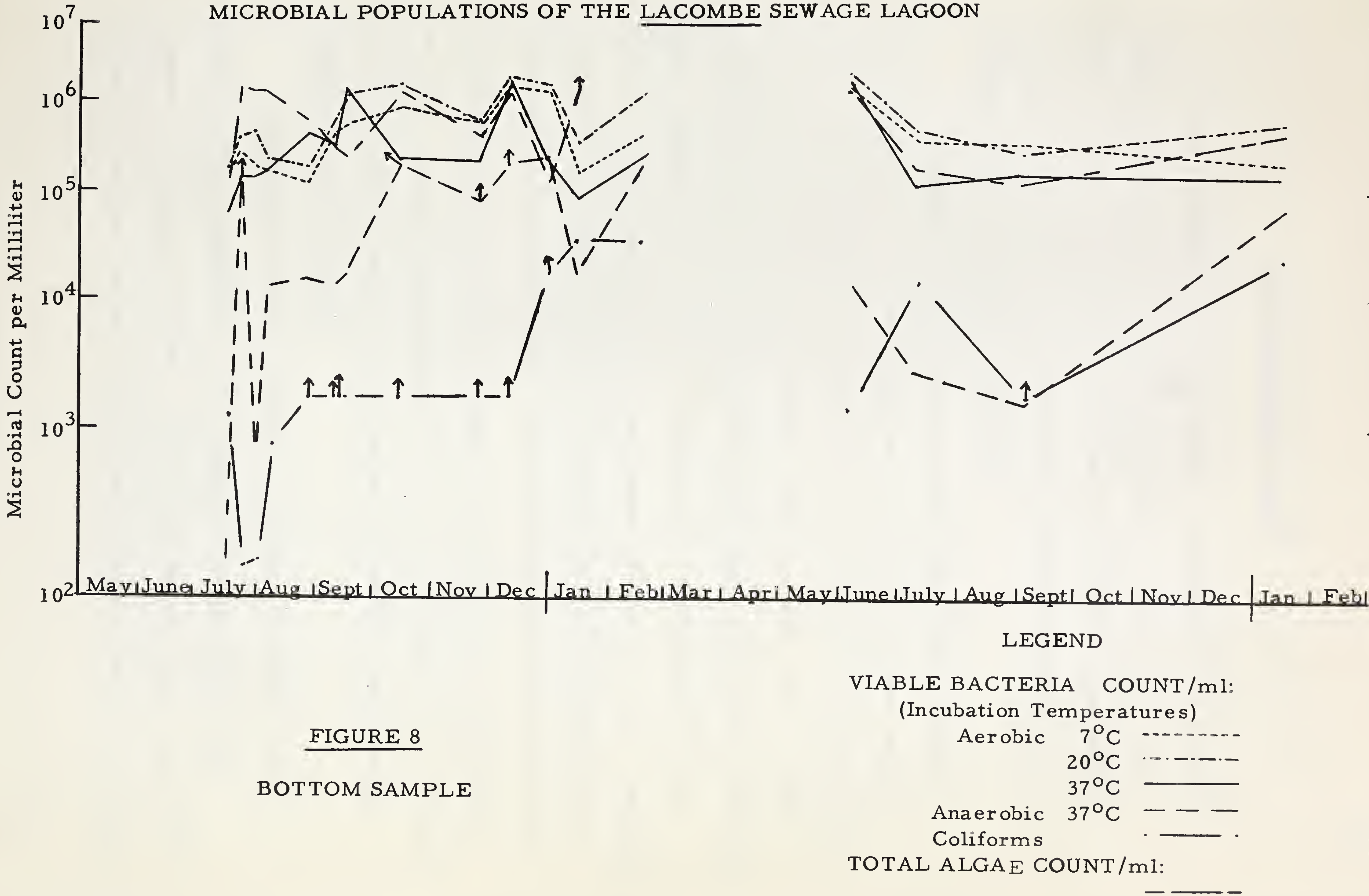


FIGURE 8

BOTTOM SAMPLE

Lacombe Sewage Lagoon

At the Lacombe raw sewage lagoon a complete year of a standard routine of operation occurs between November of each year. In the winter the lagoon is used for the storage of sewage and in the summer during the open water seasons the lagoon is allowed to overflow continuously until it is drained in November.

The calculated detention time for this "long detention" lagoon is 204.4 days., i.e., the time required to fill to the maximum depth of 5 feet. Since the lagoon is drained to the one foot level in November, the filling time is actually about 165 days, and an overflow occurs for the remaining 200 days of the year (until drained again in November of the next year). (Appendix B). During the storage of the sewage liquid in the winter of 1958-59 the liquid was transformed into the ice cover. The liquid level decreased from 12 inches to 5 inches by the end of November /58 and 7 inches of ice were formed. From November /58 to February /59 the ice and liquid increased to a depth of 15 inches each. In March /59 the water was open and overflowed when the depth reached 5 feet. Overflow continued until drainage time in November /59 and this completed the standard period of operation.

Sampling occurred for a period of 19 months from July 3/58 to January 13/60. (Appendix A). The majority of samples were taken between 10:30 AM and 1:00 PM. Both top and bottom samples were taken during the overflow seasons, but after the November drainage of the lagoon

and the formation of the ice cover only single samples were taken. The location for sampling was in the body of the lagoon approximately 40 feet from the south bank and south of the inlet which is in the bottom at the centre of the lagoon. (Appendix C). This sampling position was used from July 3/58 to March 24/59. Samples taken from June 3/59 to January 13/60 were obtained at the outlet region. Since the only constant variable, the position of the sample was changed the study of the function of the lagoon from a microbiological point of view could not be completed on a yearly basis. The microbiological changes were then determined at the new position in the outlet region under completely new micro-environmental conditions. Thus the microbial counts will be considered under two separate headings according to the position of sampling.

The Microbial Counts During Sampling within the Body of the Lagoon from July/58 to March/59: (Tables V11, V111; Figures 7, 8, 10 - 20).

The counts of aerobes grown at 7°, 20° and 37.5°C followed a similar pattern even though the lagoon was drained in November/58. The anaerobes and coliforms showed the greatest increase in count throughout the summer and winter of 1958. The 7°C aerobes increased from 10^5 to 10^6/ml. from July to October/58 and then averaged 10^6/ml. until December/59. The count decreased from January to March/59 to about 10^5/ml. The 20°C aerobes increased from July to September/58 from

10^5 to 10^6/ml. and then fluctuated about the 10^6/ml. level until March/59. The 37.5°C aerobes also increased from 10^5 to 10^6/ml. to December/58. The count then decreased to 10^5/ml. by March/59. The result for anaerobes in the July 24/58 sample was discarded as it was considered to be due to experimental error. The anaerobic count increased from 10^2/ml. in July to 10^5/ml. in October/58. From one open water period in the late fall of 1958 to the next open water period in March 1959 the anaerobic count remained steadily near 10^5/ml. although the January/59 count was close to 10^4/ml. The Most Probable Number of coliforms was 10^2/ml. from July to the beginning of August/58. The count increased rapidly at the end of August/58 and probably reached a value of 10^4/ml. or greater (based on the trend shown during the following winter). by November/58. The total algae count was slightly below 10^6/ml. until January/59 when the algae were to numerous to count. No count was determined in February/59, but by March/59 with the open water the count was again near 10^6/ml. (Appendix E).

<u>The Microbial Counts During Sampling at the Outlet Region from June/59 to January/60:</u>

The lagoon was overflowing at a depth of 5 feet during sampling from June to September/59. The final sample in January/60 was taken under ice 15 inches thick and from a liquid depth of 9 inches. No sample was taken just before the drainage of the lagoon in November/59 which could have completed a year of standard operation. The 7°C, and 20°C aerobes, the anaerobes and the algae from the outlet samples all followed

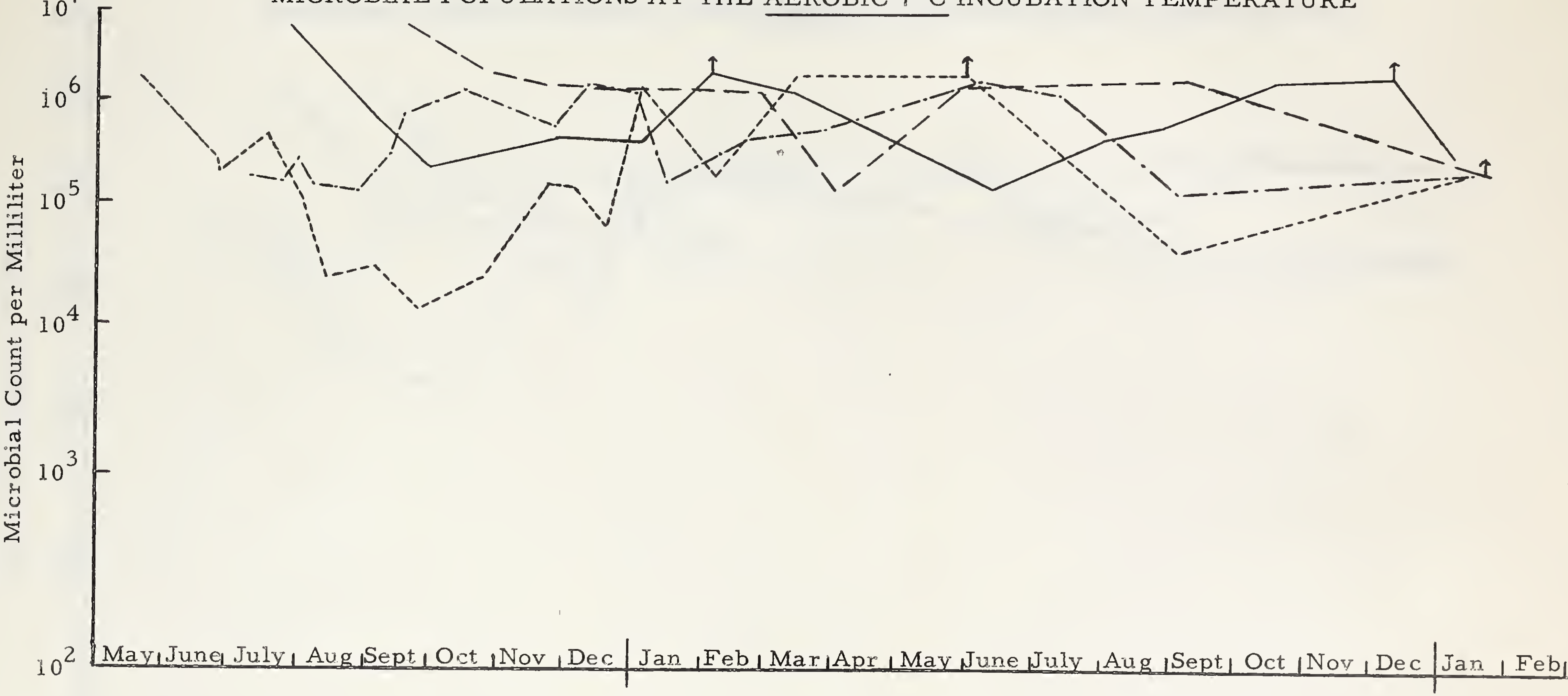
a similar pattern with their lowest counts in September/59. The 7°C and 20°C aerobes decreased from 10^6/ml. in June/59 to approximately 10^5/ml. in September/59. The aerobes of the 7°C group then remained constant until January/60, but the 20°C group increased slightly in plate count. The anaerobes followed a similar pattern decreasing to the 10^4/ml. level but returning to a level near to but slightly above that which occurred in January/59. The total count of algae followed the same pattern, but remained within the range of 10^6 to 10^5/ml. The aerobes incubated at 37.5°C decreased during June and July/59 (from 10^6 to 10^5/ml.) and then remained slightly above 10^5/ml. until January/60. The Most Probable Number of coliforms fluctuated greatly from one sampling date to the next. The June and September/59 counts were similar and low (10^3/ml.) while the July/59 and January/60 counts were similar and high (above 10^4/ml.).

During the period of July/58 to January/59 when samples were obtained in the body of the lagoon all microbial counts showed a steady increase. In 1959 the microbial count of samples from the outlet region decreased during the period June to September and then increased until January/60 when values similar to those obtained in January/59 were again recorded.

The pH was always alkaline in this lagoon. (Table XXII). The pH in the body of the liquid in the lagoon was high during the open water season of 1958, varying from 10.1 to 8.9, and under the ice cover the pH of the liquid remained alkaline with values from 8.25 to 7.55. At

the outlet sampling location the pH was only 8.7 to 9.4 during the summer and was 7.5 during the winter of 1960. The dissolved oxygen had a maximum value of 25.6 ppm in July /58. Dissolved oxygen was present until October /58. During the period of ice cover from November /58 until the open water in March /59 no dissolved oxygen was detected by the Winkler technique. Excess dissolved oxygen was present in the sample at the outlet taken during the summer of 1959 (20.4 ppm) but no dissolved oxygen was detected at this location in January 1960. The maximum temperature recorded in the body of the lagoon was $22^{\circ}C$ during July and August /58. While the ice cover was present the temperature ranged from 1° to $0^{\circ}C$. In March /59 the temperature was $2.5^{\circ}C$ and there was no ice cover. Temperatures taken at the outlet sampling location fluctuated in a similar manner.

MICROBIAL POPULATIONS AT THE AEROBIC 7°C INCUBATION TEMPERATURE



LEGEND

FIGURE 9

TOP SAMPLE

VIABLE BACTERIA COUNT/ml:

Holden ---------
Daysland — — — —
Bruderheim ————
Lacombe .—.—.—.

MICROBIAL POPULATIONS AT THE AEROBIC 7°C INCUBATION TEMPERATURE

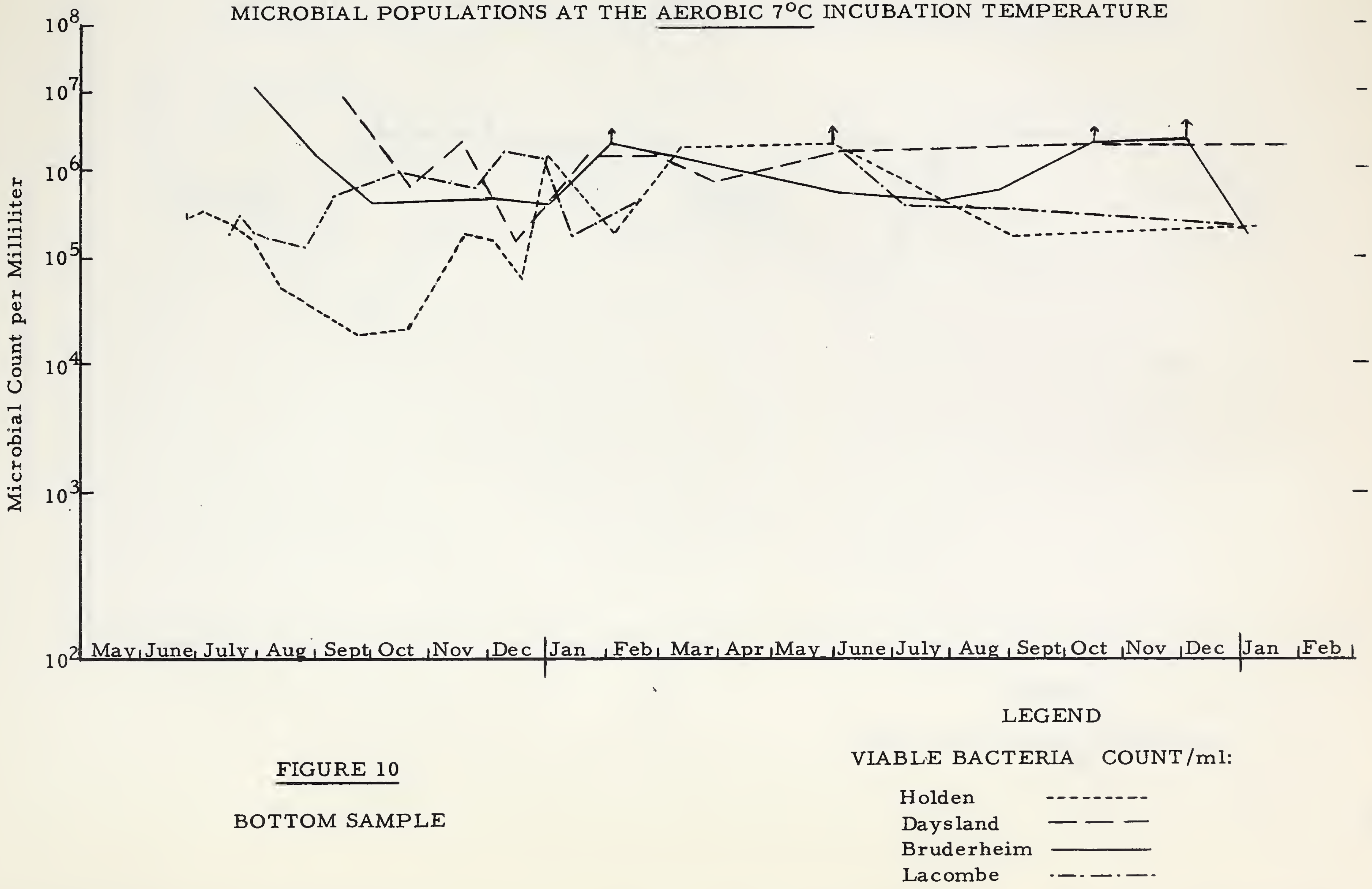


FIGURE 10

BOTTOM SAMPLE

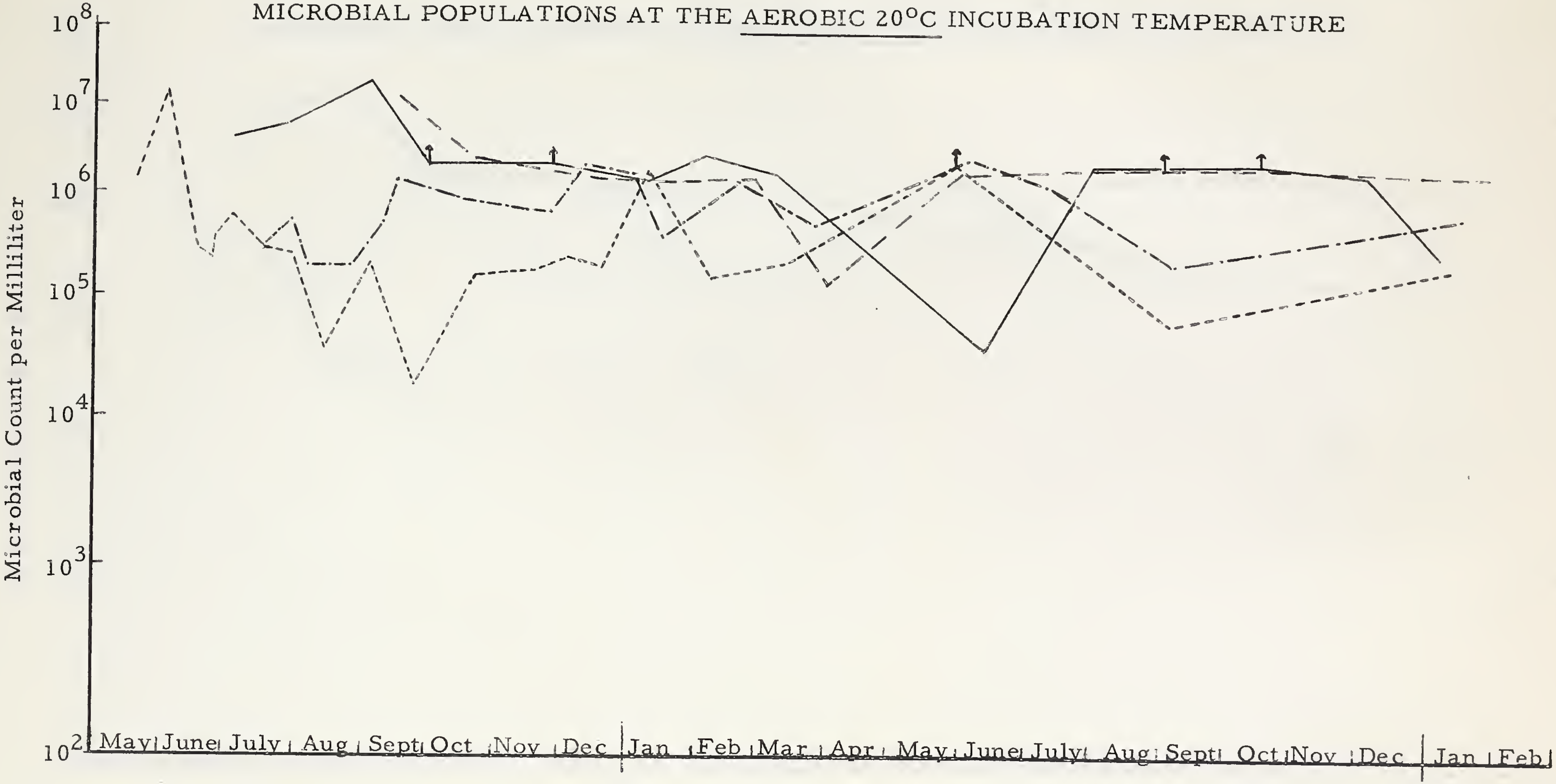


FIGURE 11

TOP SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:

Holden
Daysland
Bruderheim
Lacombe

MICROBIAL POPULATIONS AT THE AEROBIC 20°C INCUBATION TEMPERATURE

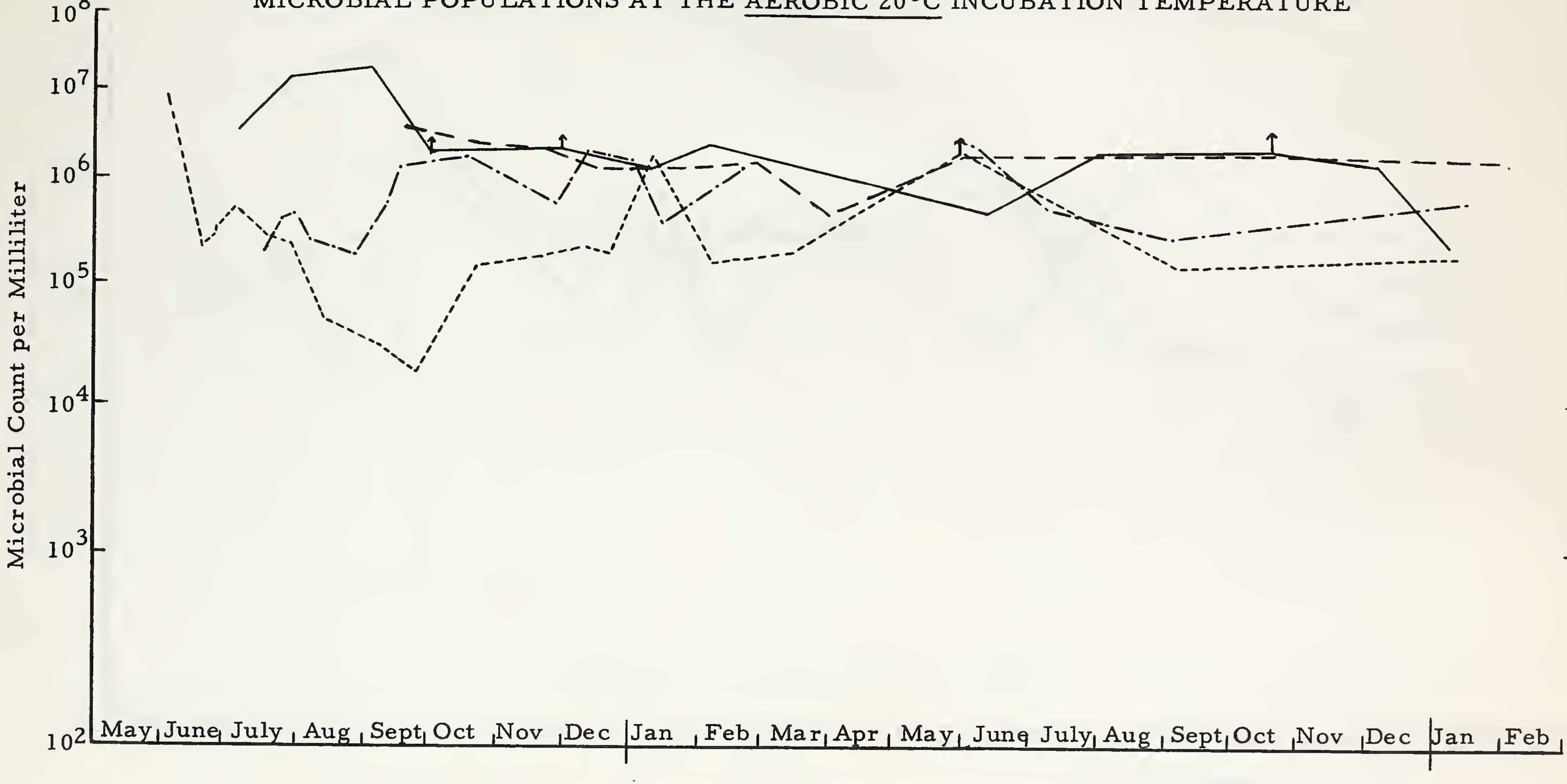


FIGURE 12

BOTTOM SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:

Holden

Daysland

Bruderheim

Lacombe

MICROBIAL POPULATIONS AT THE AEROBIC 37°C INCUBATION TEMPERATURE

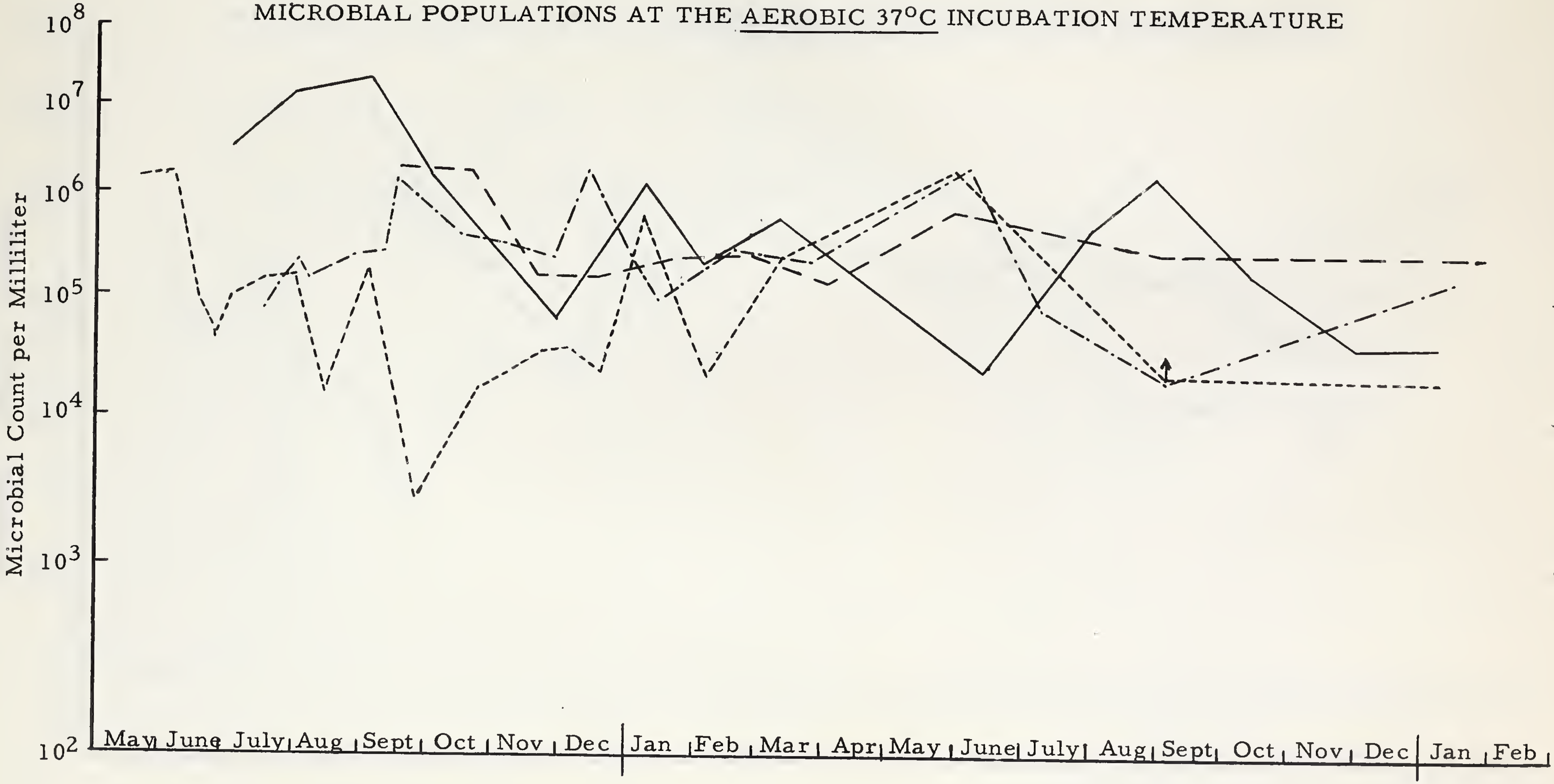


FIGURE 13

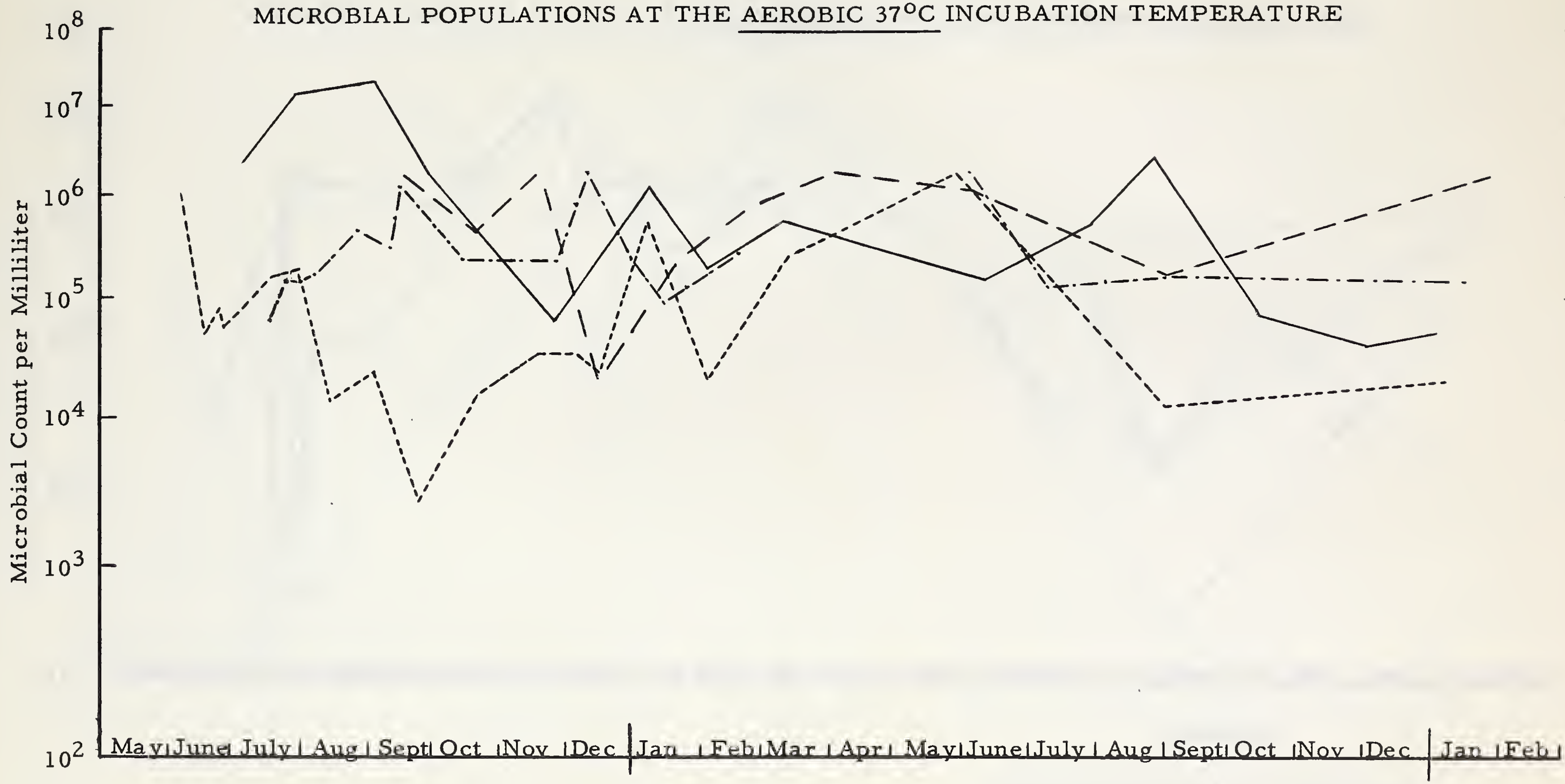
TOP SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:

Holden - - - - - - - -
Daysland — — —
Bruderheim ————
Lacombe - — - — -

MICROBIAL POPULATIONS AT THE AEROBIC 37°C INCUBATION TEMPERATURE



LEGEND

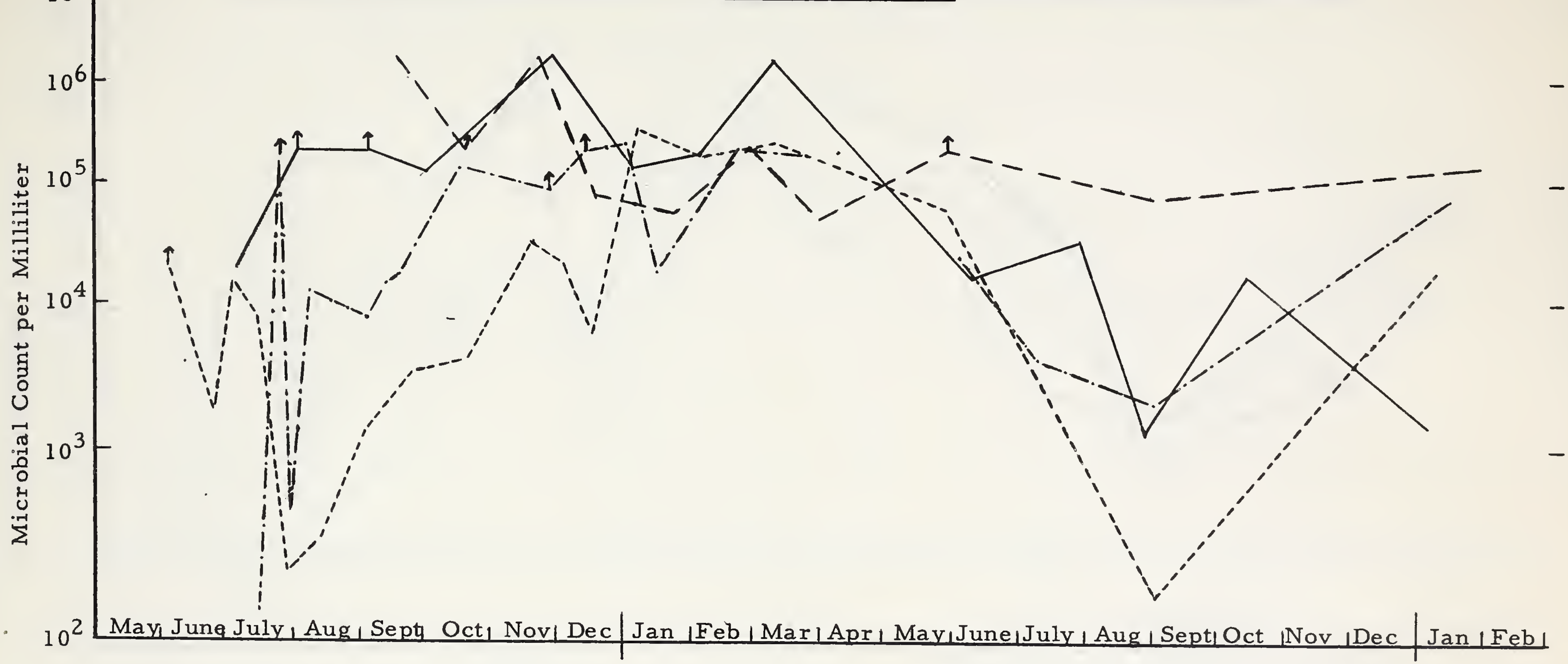
VIABLE BACTERIA COUNT/ml:

Holden - - - - - - - -
Daysland — — — —
Bruderheim ————
Lacombe —·—·—·—

FIGURE 14

BOTTOM SAMPLE

MICROBIAL POPULATIONS AT THE ANAEROBIC 37°C INCUBATION TEMPERATURE



LEGEND

VIABLE BACTERIA COUNT/ml:

Holden - - - - - - - - -
Daysland — — —
Bruderheim ————
Lacombe -·-·-·-·-

FIGURE 15

TOP SAMPLE

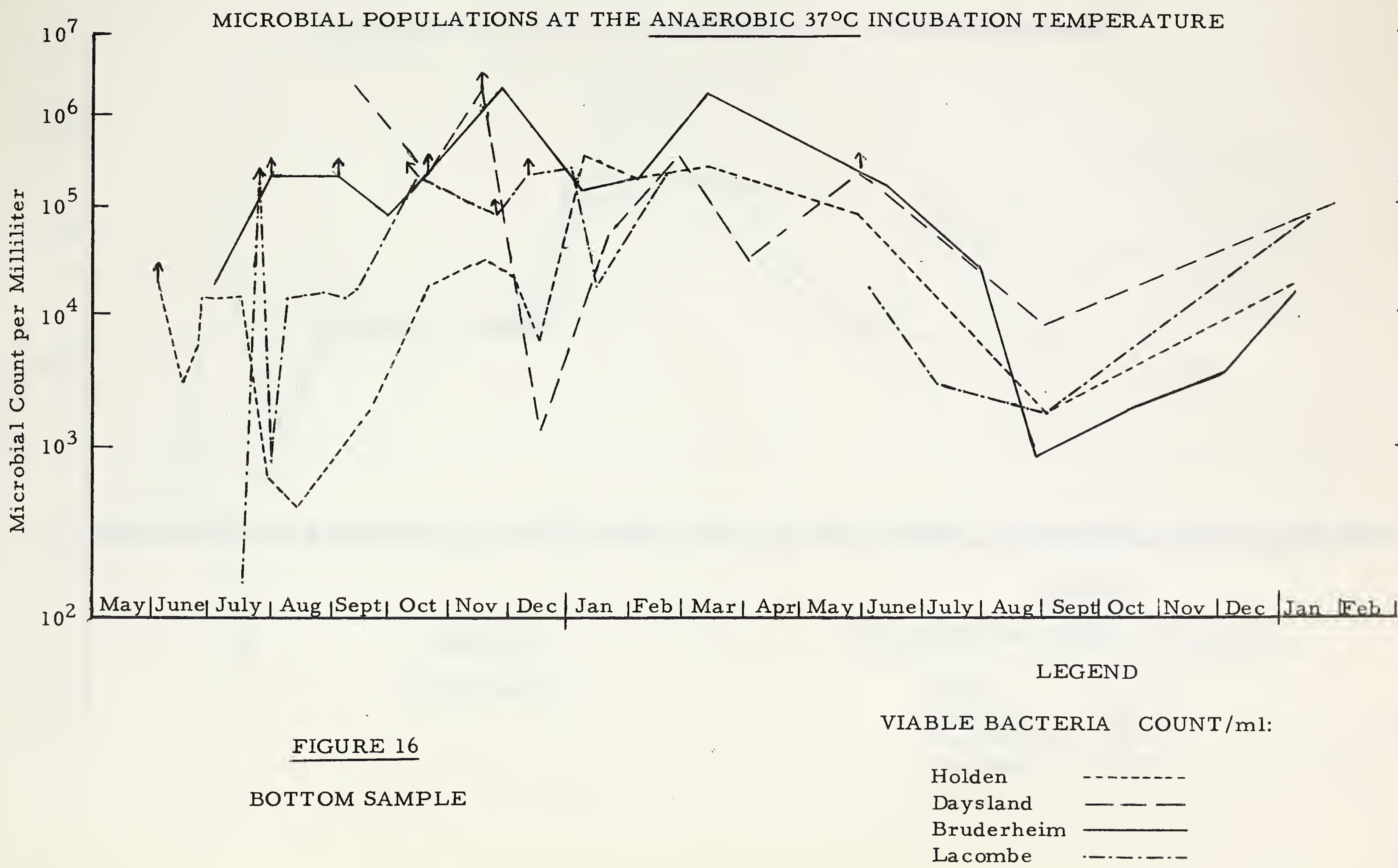


FIGURE 16

BOTTOM SAMPLE

COLIFORM BACTERIAL POPULATIONS IN THE SEWAGE LAGOONS

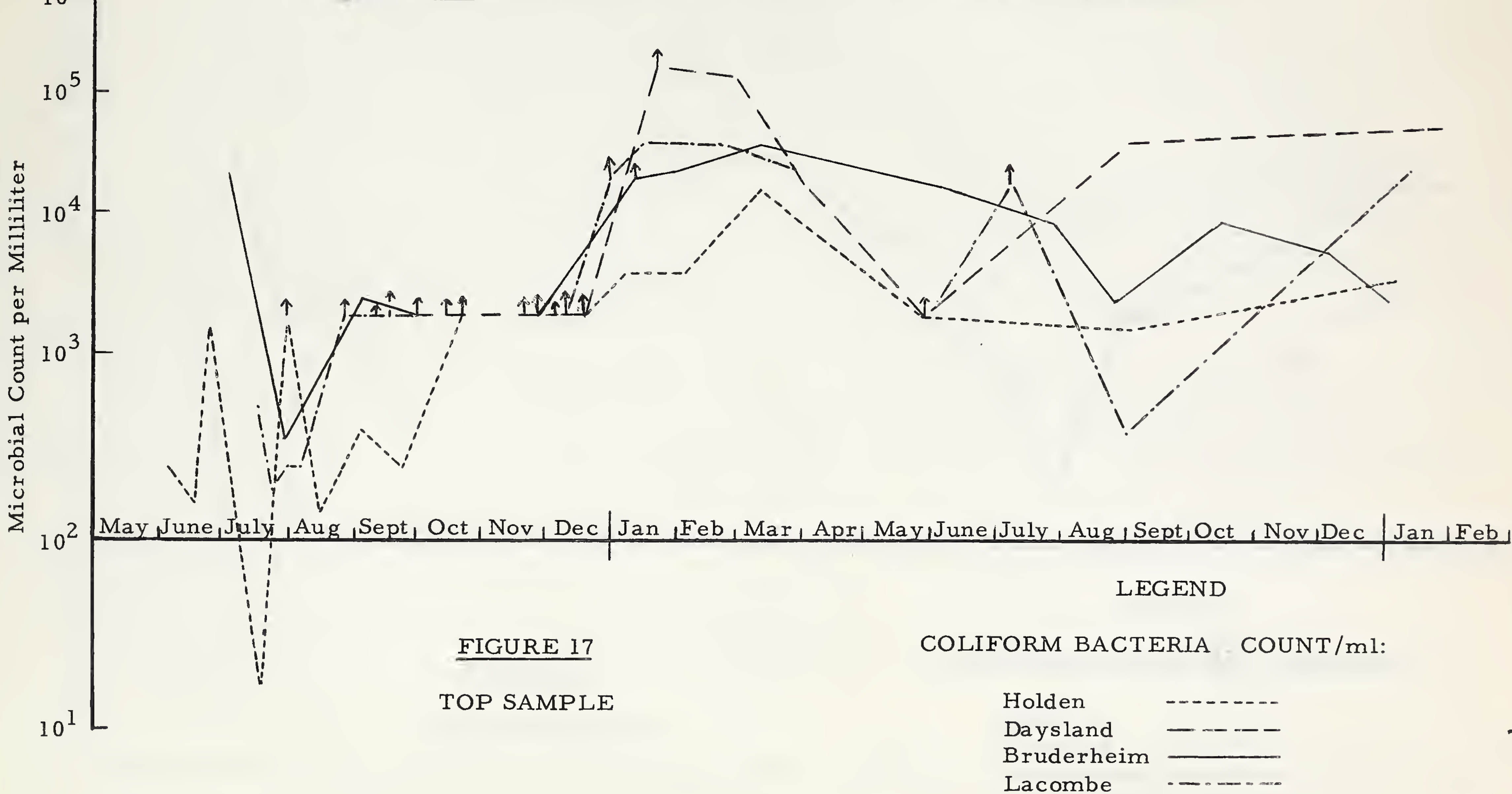


FIGURE 17

TOP SAMPLE

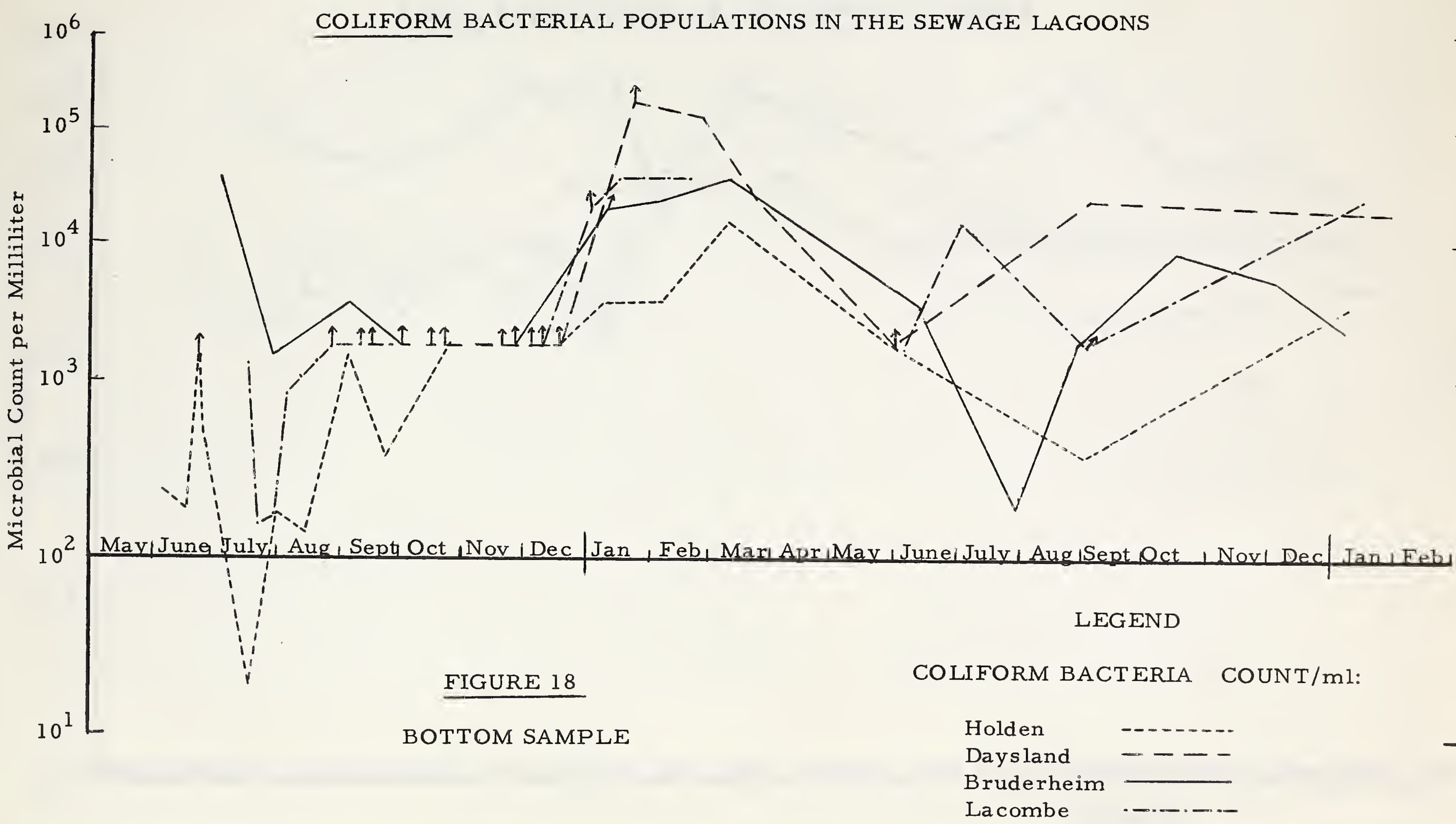


FIGURE 18

BOTTOM SAMPLE

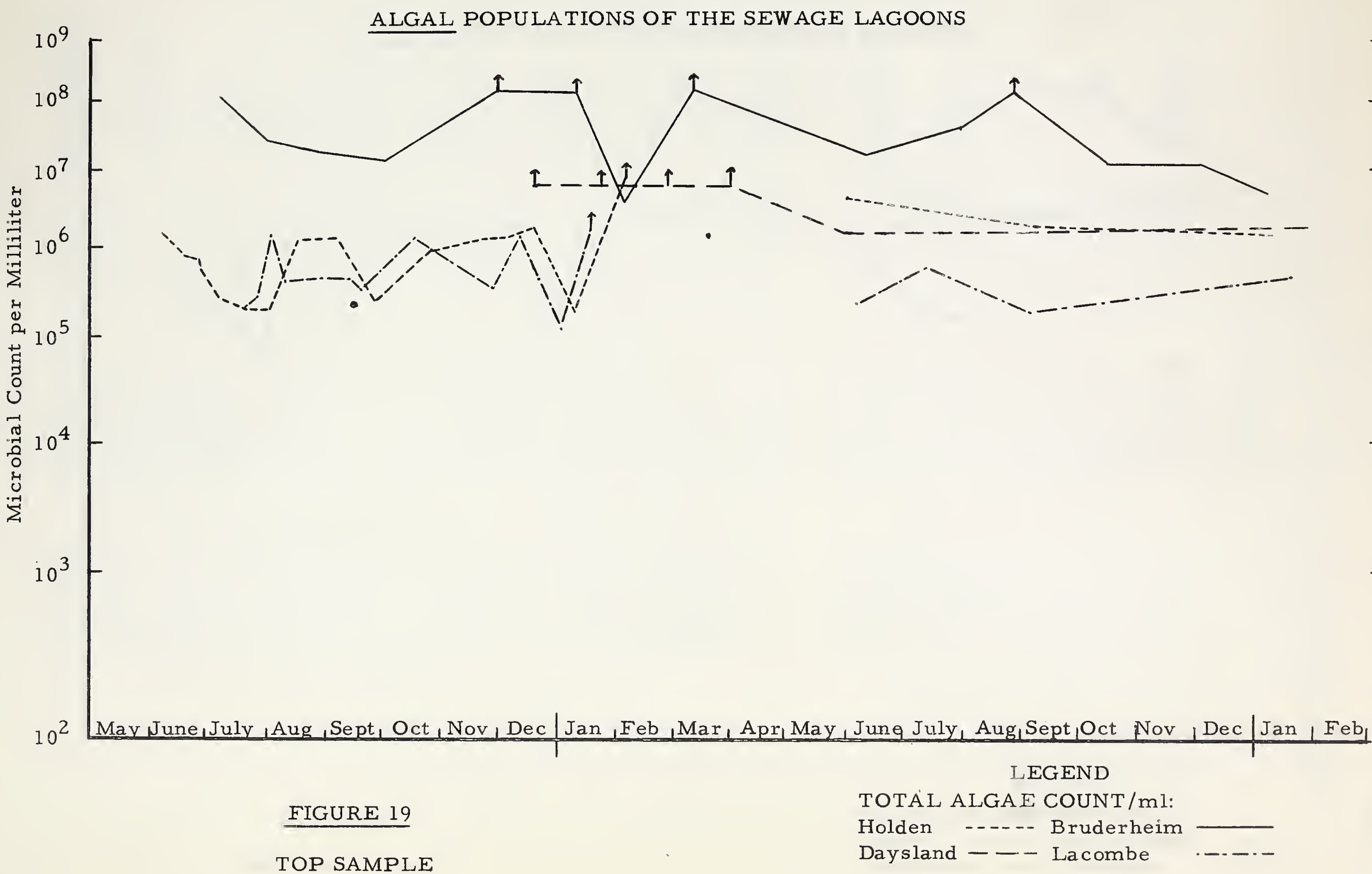
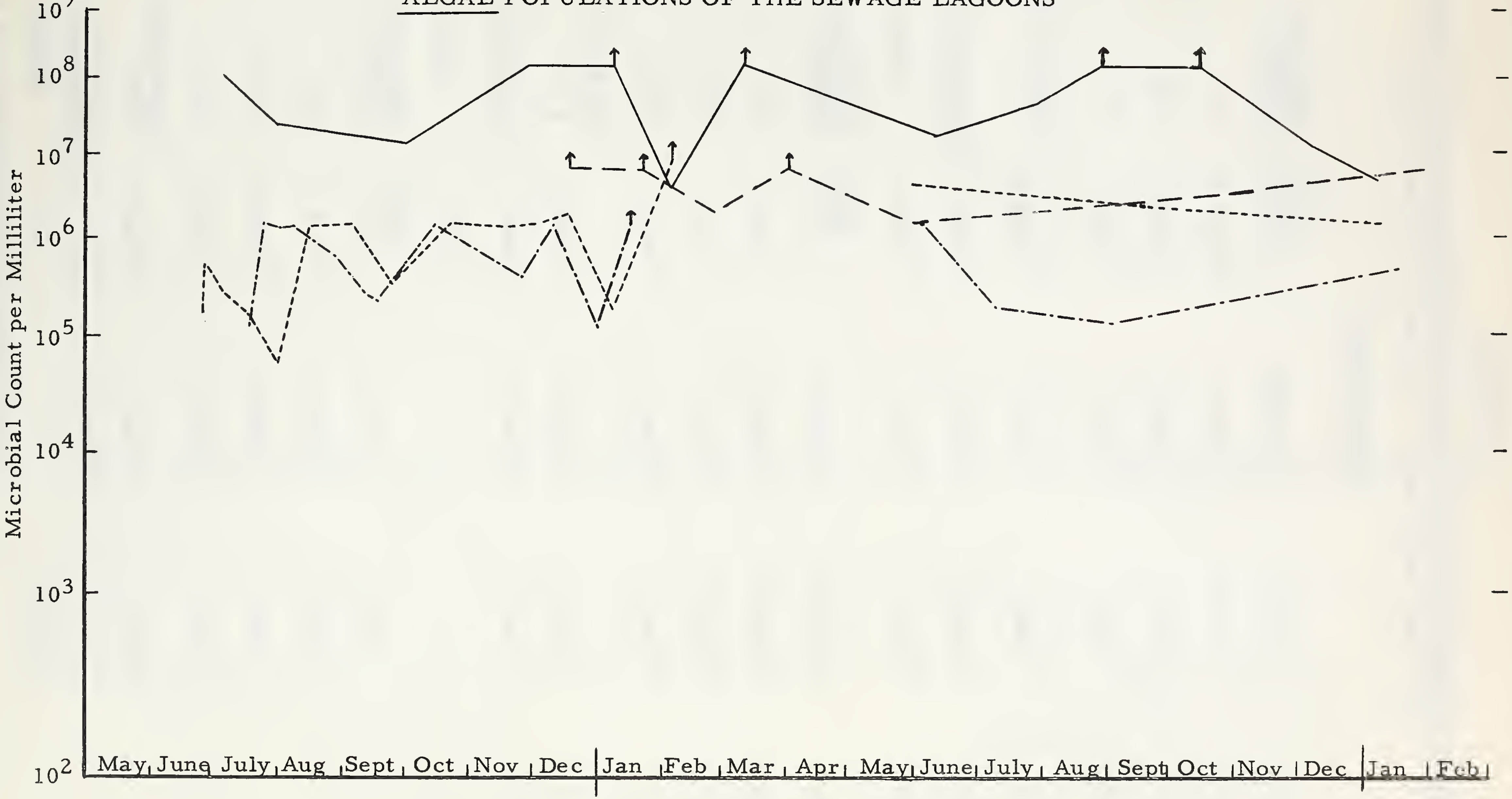


FIGURE 19

TOP SAMPLE

ALGAL POPULATIONS OF THE SEWAGE LAGOONS



LEGEND

TOTAL ALGAE COUNT/ml:
Holden ------- Bruderheim ———
Daysland — — — Lacombe -·-·-

FIGURE 20

BOTTOM SAMPLE

TABLE IX

MICROBIAL POPULATIONS IN THE STONY PLAIN (#3) SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

TOP SAMPLE

BACTERIA: AEROBIC	1958 AUG 13	AUG 21	AUG 21	AUG 21
7°C	>3.0×10^6	7.0×10^5	8.5×10^5	1.3×10^6
20°C	>3.0×10^6	1.3×10^7	1.2×10^7	1.9×10^7
37°C	>3.0×10^6	1.1×10^7	1.5×10^7	1.7×10^7
ANAEROBIC 37°C	8.0×10^2	5.0×10^3	3.0×10^3	2.0×10^3
COLIFORMS:	3.5×10^2	3.5×10^2	9.2×10^2	3.5×10^2
ALGAE:	6.0×10^5	8.0×10^4	9.0×10^4	2.6×10^5

BACTERIA: AEROBIC	1958 SEPT 2	SEPT 30	OCT 27	DEC 9
7°C	2.2×10^5	1.0×10^4	>3.0×10^6	2.3×10^6
20°C	1.1×10^7	8.2×10^5	>3.0×10^6	1.9×10^6
37°C	1.2×10^7	1.4×10^5	2.6×10^6	1.3×10^6
ANAEROBIC 37°C	8.3×10^2	7.8×10^3	>3.0×10^5	6.0×10^5
COLIFORMS:	3.5×10^2	<1.8×10^1	>2.4×10^3	>2.4×10^3
ALGAE:	1.4×10^6	*	*	4.0×10^5

BACTERIA: AEROBIC	1959 JUNE 23	AUG 25	DEC 9
7°C	5.3×10^5	2.0×10^5	3.2×10^5
20°C	>3.0×10^5	6.8×10^5	4.7×10^5
37°C	4.8×10^5	5.2×10^5	1.6×10^5
ANAEROBIC 37°C	7.8×10^5	1.5×10^4	1.3×10^5
COLIFORMS:	3.5×10^4	3.5×10^4	4.9×10^3
ALGAE:	*	*	1.1×10^7

* Too few Algae for an accurate count.

MICROBIAL POPULATIONS IN THE STONY PLAIN (#3) SEWAGE LAGOON

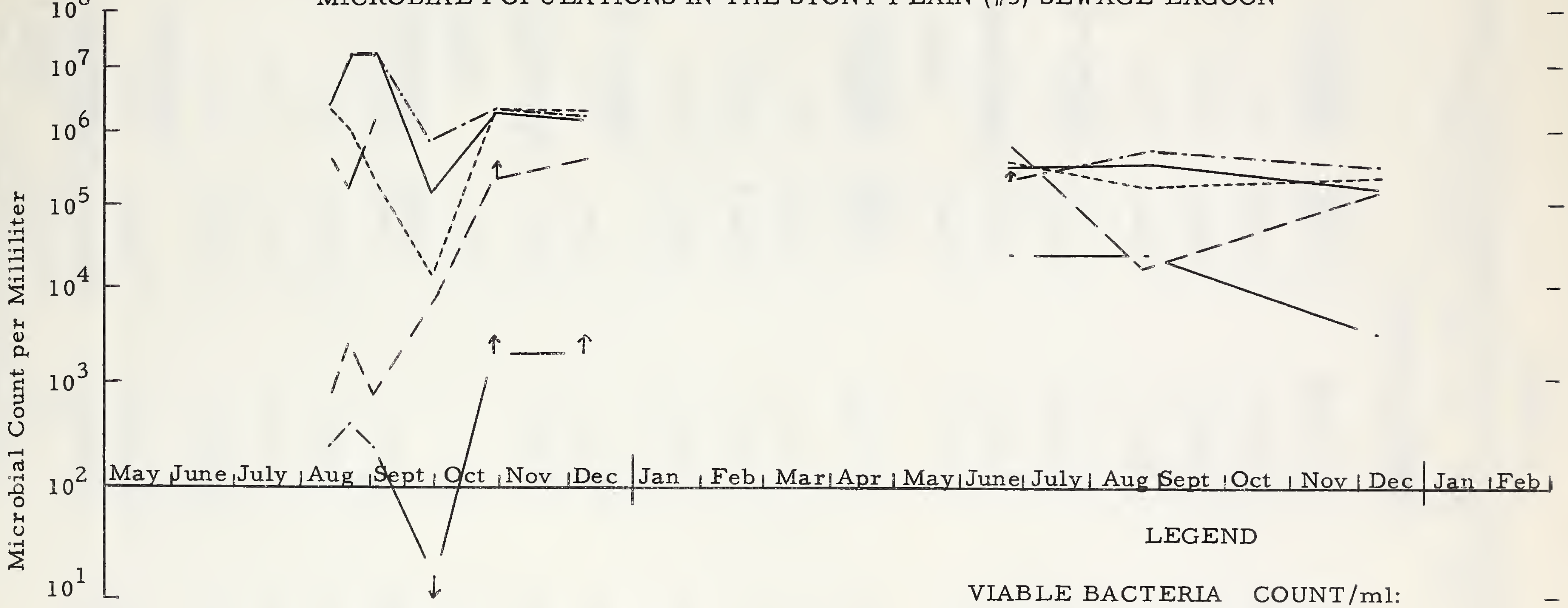


FIGURE 21

TOP SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C
20°C
37°C
Anaerobic 37°C
Coliforms
TOTAL ALGAE COUNT/ml:

TABLE X

MICROBIAL POPULATIONS IN THE STONY PLAIN (#3) SEWAGE LAGOON
(Viable Bacteria Count /ml Total Algae Count /ml)

BOTTOM SAMPLE

BACTERIA: AEROBIC	1958 AUG 13	AUG 21	AUG 21	AUG 21
7°C	>$3.0x10^6$	$5.2x10^5$	$7.3x10^5$	$1.3x10^6$
20°C	>$3.0x10^6$	$9.6x10^6$	$1.5x10^7$	$1.8x10^7$
37°C	>$3.0x10^6$	$1.0x10^7$	$1.8x10^7$	$1.5x10^7$
ANAEROBIC 37°C	$7.0x10^2$	$2.0x10^4$	$8.0x10^2$	$2.0x10^4$
COLIFORMS:	$1.3x10^2$	$1.6x10^3$	$3.5x10^2$	$5.4x10^2$
ALGAE:	$5.0x10^5$	$4.0x10^5$	$1.6x10^5$	$3.8x10^5$

BACTERIA: AEROBIC	1958 SEPT 2	SEPT 30	DEC 9
7°C	$2.1x10^5$	$2.0x10^4$	$3.2x10^6$
20°C	$7.6x10^6$	$1.6x10^5$	$3.1x10^6$
37°C	$8.0x10^6$	$5.0x10^2$	$2.1x10^6$
ANAEROBIC 37°C	$1.0x10^3$	$1.7x10^4$	>$3.0x10^7$
COLIFORMS:	$2.2x10^2$	$2.0x10^0$	>$2.4x10^3$
ALGAE:	$7.5x10^5$	*	$1.7x10^6$

BACTERIA: AEROBIC	1959 MAR 3	JUNE 23	AUG 25	DEC 9
7°C	$4.3x10^5$	$1.5x10^5$	$3.0x10^5$	$1.0x10^5$
20°C	$1.2x10^6$	$7.3x10^4$	$6.0x10^5$	$2.4x10^5$
37°C	$2.0x10^5$	$1.5x10^5$	$4.7x10^5$	$8.4x10^4$
ANAEROBIC 37°C	$4.2x10^4$	$3.7x10^5$	$5.0x10^4$	$1.4x10^4$
COLIFORMS:	$5.4x10^5$	>$2.4x10^4$	$1.7x10^4$	$1.3x10^4$
ALGAE:	$2.5x10^5$	lost	*	$5.2x10^7$

* Too few Algae for an accurate count.

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MICROBIAL POPULATIONS IN THE STONY PLAIN (#3) SEWAGE LAGOON

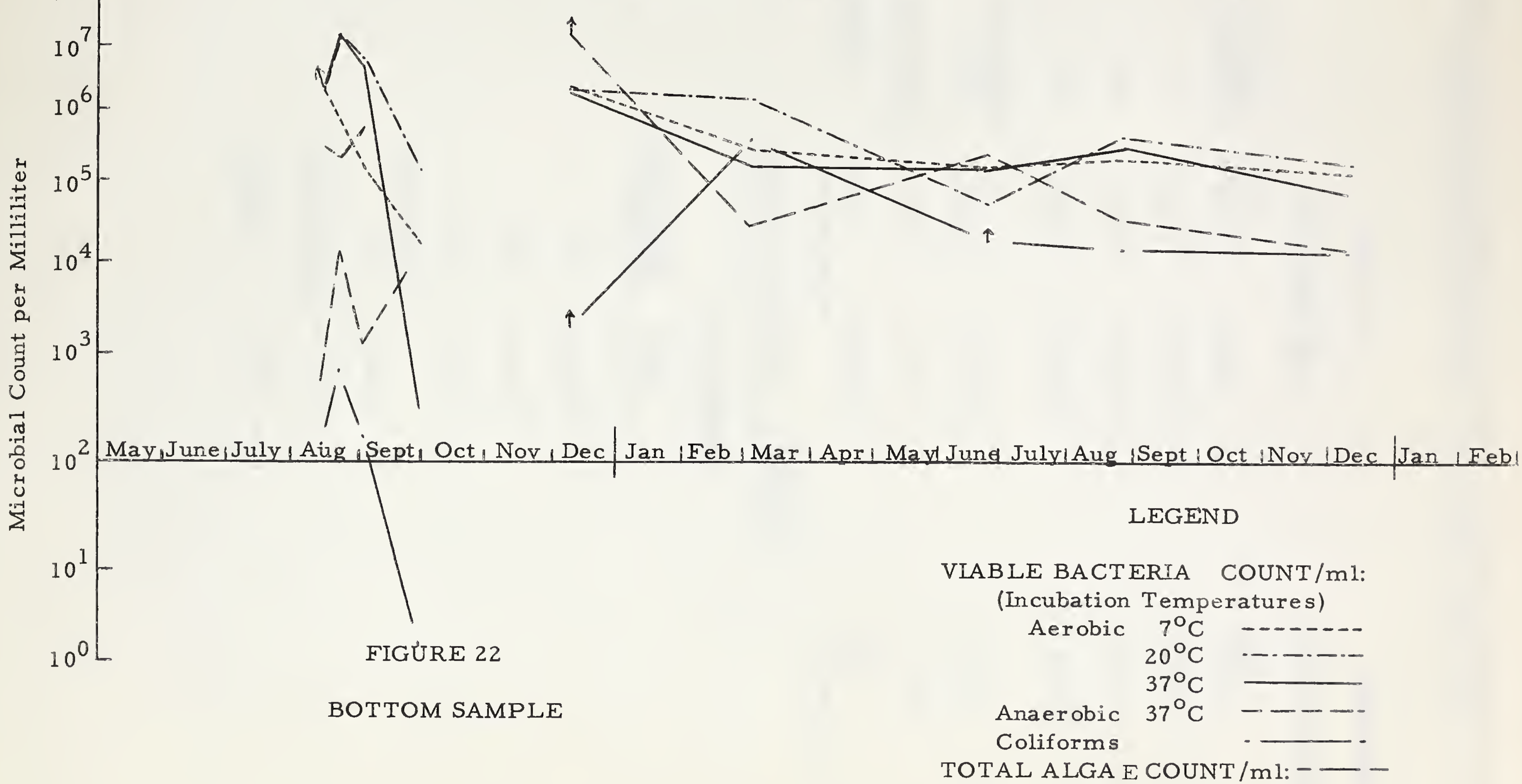


FIGURE 22

BOTTOM SAMPLE

MICROBIAL POPULATIONS OF THE STONY PLAIN (#4) SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algæ Count /ml)

TABLE XI — TOP SAMPLE / TABLE XII — BOTTOM SAMPLE

	TABLE XI TOP SAMPLE 1959 AUG 25	TABLE XI TOP SAMPLE DEC 9	TABLE XII BOTTOM SAMPLE 1959 AUG 25	TABLE XII BOTTOM SAMPLE DEC 9
BACTERIA: AEROBIC				
7°C	1.3×10^{3}	2.2×10^{5}	7.0×10^{2}	6.7×10^{4}
20°C	6.0×10^{3}	2.0×10^{5}	7.0×10^{3}	5.4×10^{4}
37°C	1.3×10^{3}	$>3.0 \times 10^{4}$	2.2×10^{3}	1.0×10^{3}
ANAEROBIC 37°C	3.2×10^{1}	1.2×10^{2}	1.2×10^{1}	2.3×10^{2}
COLIFORMS:	2.3×10^{0}	4.5×10^{2}	2.3×10^{0}	4.5×10^{2}
ALGAE:	none recognizable	8.5×10^{6}	none recognizable	3.2×10^{6}

STONY PLAIN NO. 1 LAGOON

TOP SAMPLE

BACTERIA: AEROBIC	1958 OCT 27
7°C	$>3.0 \times 10^{6}$
20°C	$>3.0 \times 10^{6}$
37°C	3.5×10^{6}
ANAEROBIC 37°C	$>3.0 \times 10^{5}$
COLIFORMS:	$>2.4 \times 10^{3}$
ALGAE:	Debris only

Stony Plain Sewage Lagoons

This lagoon system consists of three short detention lagoons and one long detention lagoon. The sewage liquid flows continuously through the first three lagoons. Lagoons number 1 and 2 are constructed with the same dimensions having a depth of 5 feet and a calculated detention time of 0.93 days. Lagoon 3 has a depth of 5 feet and a calculated detention time of 2.6 days. The fourth lagoon which is used as a storage lagoon was constructed more recently and has a depth of 6 feet and the calculated detention time is 187 days.

Only one sample was taken from the first lagoon while all three lagoons were in normal operation. This sample was taken from the top on October 27/58. The microbial counts obtained from this sample are shown in Table X1, and the various environmental factors in Table XX111.

No sampling was done in lagoon 2. From approximately the middle of August to September 30/58 sewage flow occurred through lagoons 1 and 2 into a ditch bypassing lagoon 3. On October 27/58 and following that date sewage again flowed through all three lagoons continuously.

The third short detention lagoon was not in continuous operation. The inlet was plugged and the lagoon bypassed for the months of August and September/58. During this time samples were taken at the outlet region although there was no inflow or overflow. The stagnant liquid decreased in volume by evaporation only. No new nutrients or fresh inoculum of microorganisms were added to the sewage fluid during

this time. Results obtained from samples taken from this lagoon during August and September/58 demonstrate what occurs when sewage fluid is stored during summer. During this stagnant period the numbers of aerobic bacteria obtained at 7°, 20° and 37.5° C decreased in a similar manner. (e.g., 7° C; from 10^{6} to 10^{4} ml. and the 20°C; from 10^{7} to 10^{5}/ml.) The 37.5° C aerobes showed the greatest change in count. The top sample decreased from 10^{7} to 10^{5}/ml., while the bottom sample decreased from 10^{7} to 10^{2}/ml. The coliforms showed a decrease in numbers similar to but less pronounced than the aerobes at 37.5°C. The anaerobes showed a 10-fold increase in count during the same period. The total algae count decreased from 10^{6} to 10^{5}/ml and at the end of the period were to few to count accurately.

The environmental factors were measured during the months the lagoon fluid was stagnant and evaporating. On August 13/58 the temperature was 21.5° C. The pH was 7.7 and there was 10.5 ppm of dissolved oxygen present. In the next two samples the temperature was 16.8° C and 14.5° C and the fluid had an alkaline reaction at pH 7.6. No dissolved oxygen was detected in these samples. When the final samples of the stagnant period (September 30/58) were taken the temperature was 7° C, the pH alkaline at 8.2 and dissolved oxygen was again present at 17.4 ppm.

When the October 27/58 sample was taken the 3 lagoons were again functioning in series. The third lagoon was flowing into a ditch. Continuous overflow occurred through the winter. The ice cover was 8 inches thick and the liquid 4 feet deep.

The sample of October/58 shows the recovery of the third lagoon as a result of resumption of normal operation. Top samples obtained from the first and third lagoon contained comparable microbial populations. No algae were evident in the first lagoon, but they were present in the third lagoon though to few to count accurately. There was only 0.5 ^{o}C difference in temperature and no dissolved oxygen was present in either lagoon. The pH decreased from 7.6 in the first lagoon to 7.25 in the third lagoon.

During the period of standard routine of operation from October/58 to December/60 both top and bottom samples were obtained from the outlet region at the north bank. In October/58 only a top sample and in March/59 only a bottom sample was taken.

All the microbial counts remained at relatively high values though there was a gradual decrease from the fall of 1958 to the winter of 1959. The aerobes grown at incubation temperatures of 7^{o}, 20^{o} and 37.5^{o} C. decreased in a similar pattern from the high of 10^6/ml. in October/58 fluctuating between 10^6 to 10^5/ml. until December/60 when the counts were near 10^5/ml. The anaerobes increased to their maximum count (10^7/ml.) in December/58 then decreased to 10^4/ml in March /59 and fluctuated between 10^4/ml. to 10^5/ml. until December/60. The Most Probable Number of coliforms in March/59 was 10^5/ml therefore it is considered that the coliform count probably had reached this value in October/58 after the continuous overflow commenced. The count decreased from 10^5/ml. to 10^4/ml. by June/59, remained steady until August/59 and then -

decreased to slightly below 10^4/ml. by December/60. The algae were to few to count accurately in the October /58 sample, but by December/59 the count was 10^6/ml. in 4 feet of liquid covered with 8 inches of ice. The algae decreased to slightly above 10^5/ml. by March/59. No results were obtained in June/59. In August/59 the algae were too few to count accurately, but by December/60 the count was 10^7/ml(liquid 4';ice 8").

The long detention lagoon, the fourth lagoon, was brought into service to store sewage flowing continuously from the third short detention lagoon. The initial filling began in April/59 and continued until the Spring of 1960 when the lagoon was drained to the one foot level.

Top and bottom samples were taken at the outlet region on the north bank on August 25/59 and on December 9/59.

The microbial counts of all groups were similar in the top and bottom sample in August/59. On December/59 when the final samples were taken, the aerobes at 7^{o}, 20^{o} and 37.5^{o} C. all had a 10-fold greater count in the top sample, than in the bottom sample., while the other microbial groups had similar counts in both samples. At this time the lagoon was stagnant with 4.5 feet of liquid under 1 foot of ice. The temperature of the liquid was 0.5^{o}C. Nutrients and organisms were being continuously added to the lagoon by way of the influent. During the period August to December/59 all the microbial counts increased greatly. Aerobes and anaerobes incubated at 37.5^{o} C showed a 10-fold increase. The aerobes of 7^{o} C and 20^{o} C and the coliforms increased 100-fold. The greatest change however, was shown in the total algae count.

The counts for all microbial groups were much lower in the fourth lagoon than in the third lagoon in August/59. By December/59 the microbial populations of both the third and fourth lagoons had increased, however, the rate of increase was more rapid in the fourth lagoon.

Environmental factors in lagoons 3 and 4 showed very significant alterations over the period August/59 and December/59. In August/59 the change in each factor between lagoons 3 and 4 was as follows. The temperature increased from 12^{o} C to 14^{o}C; the pH increased from 7.4 to 8.4. The dissolved oxygen was 8.8 ppm in both lagoons. The depth of liquid was 5 feet and 4 feet respectively. In December/59 the changes between lagoon 3 and 4 were as follows: The temperature decreased from 3^{o} C to 0.5^{o}C, the pH increased from 7.5 to 7.75. The most significant change was the concentration of dissolved oxygen. The third lagoon had no dissolved oxygen in 4 feet of liquid covered with 8 inches of ice whereas the fourth lagoon with 4.5 feet of liquid and 1 foot of ice contained 6.3 ppm of dissolved oxygen.

MICROBIAL POPULATIONS OF THE DRAYTON VALLEY (#1) SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

TABLE XIII

TOP SAMPLE

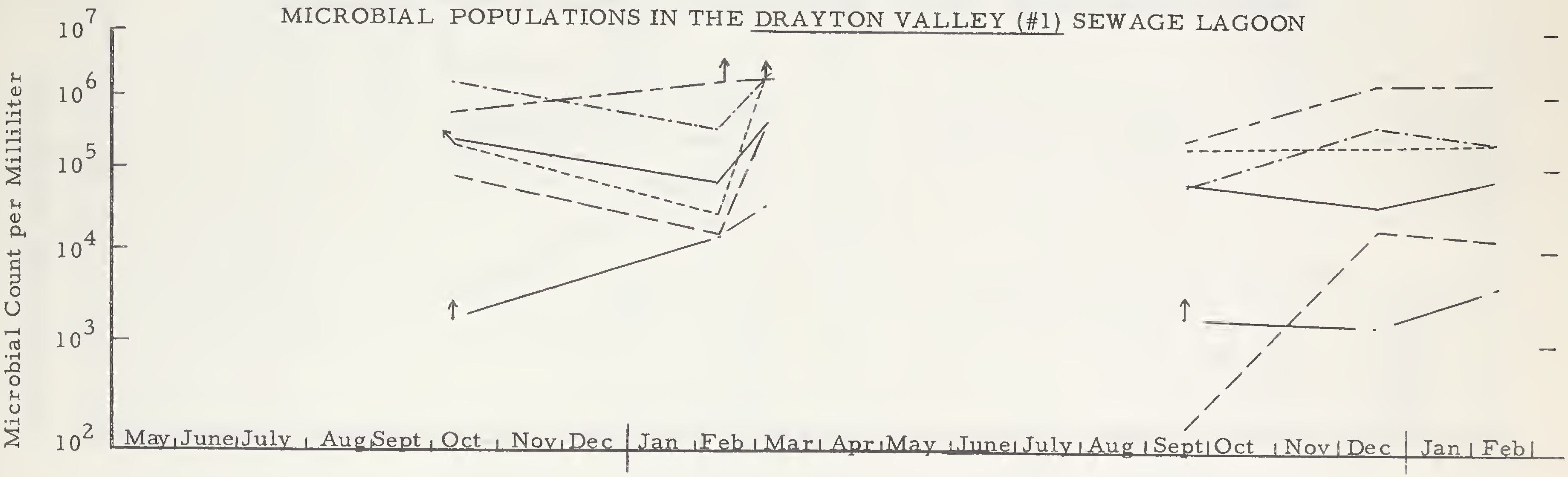
BACTERIA:	1958	1959		
AEROBIC	OCT 7	FEB 10	MAR 3	SEPT 16
7°C	>$3.0x10^5$	$4.1x10^4$	$1.7x10^6$	$2.5x10^5$
20°C	$2.0x10^6$	$5.1x10^5$	$2.1x10^6$	$7.6x10^4$
37°C	$4.0x10^5$	$8.3x10^4$	$6.0x10^5$	$7.7x10^4$
ANAEROBIC 37°C	$9.0x10^4$	$1.8x10^4$	$5.4x10^5$	$1.9x10^2$
COLIFORMS:	>$2.4x10^3$	$1.3x10^4$	$5.4x10^4$	>$2.4x10^3$
ALGAE:	$7.5x10^5$	>$1.9x10^6$	>$1.9x10^6$	$3.5x10^5$

BACTERIA:	1959		1960	
AEROBIC	DEC 14	DEC 14	FEB 9	FEB 9
7°C	$3.2x10^5$	$2.6x10^5$	$4.1x10^5$	$2.1x10^5$
20°C	$5.6x10^5$	$5.9x10^5$	$3.5x10^5$	$2.7x10^5$
37°C	$6.9x10^4$	$2.9x10^4$	$1.1x10^5$	$6.5x10^4$
ANAEROBIC 37°C	$7.0x10^4$	$1.9x10^3$	$1.3x10^4$	$2.7x10^4$
COLIFORMS:	$2.3x10^3$	$7.8x10^2$	$1.3x10^3$	$7.9x10^3$
ALGAE:	$1.4x10^6$	$1.6x10^6$	$1.4x10^6$	$1.9x10^6$

TABLE XIV

BOTTOM SAMPLE

BACTERIA:	1958	1959	
AEROBIC	OCT 7	FEB 10	MAR 3
7°C	>$3.0x10^5$	$8.6x10^5$	$4.9x10^5$
20°C	>$3.0x10^6$	$1.5x10^6$	$6.8x10^5$
37°C	$1.5x10^5$	>$3.0x10^5$	$9.1x10^4$
ANAEROBIC 37°C	$1.3x10^5$	$1.8x10^4$	$2.5x10^5$
COLIFORMS:	>$2.4x10^3$	$9.2x10^4$	$2.4x10^4$
ALGAE:	$6.5x10^5$	$5.0x10^4$	>$1.9x10^6$



LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C
20°C
37°C
Anaerobic 37°C
Coliforms
TOTAL ALGAE COUNT/ml:

FIGURE 23

TOP SAMPLE

MICROBIAL POPULATIONS IN THE DRAYTON VALLEY (#1) SEWAGE LAGOON

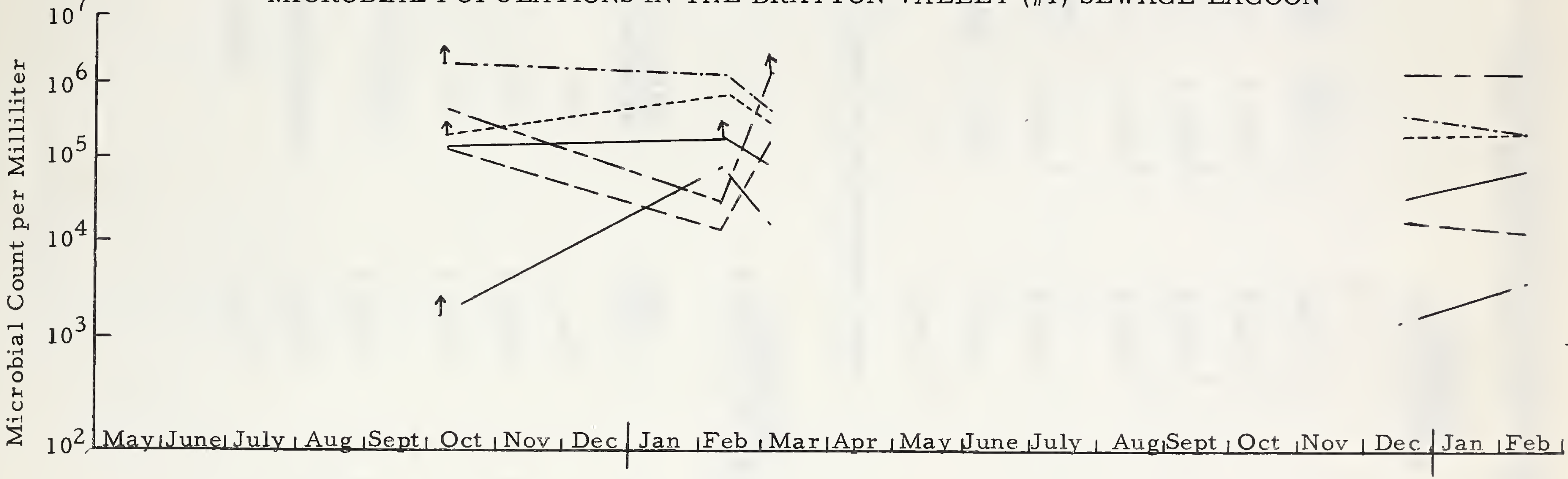


FIGURE 24

BOTTOM SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:

(Incubation Temperatures)

Aerobic 7°C

20°C

37°C

Anaerobic 37°C

Coliforms

TOTAL ALGAE COUNT/ml:

MICROBIAL POPULATIONS OF THE DRAYTON VALLEY (#2) SEWAGE LAGOON

(Viable Bacteria Count /ml Total Algae Count /ml)

TABLE XV
TOP SAMPLE

BACTERIA: AEROBIC	1959 SEPT 16	DEC 14	1960 FEB 9	FEB 9
7°C	$3.5x10^3$	$5.8x10^5$	$8.8x10^4$	$8.0x10^4$
20°C	$3.3x10^4$	$8.0x10^5$	$1.5x10^5$	$1.8x10^5$
37°C	$4.1x10^4$	$8.2x10^4$	$6.3x10^4$	$8.5x10^4$
ANAEROBIC 37°C	$1.8x10^2$	$5.1x10^3$	$1.2x10^3$	$1.2x10^3$
COLIFORMS:	$1.3x10^1$	$7.9x10^3$	$1.7x10^2$	$5.4x10^2$
ALGAE:	*	$3.8x10^6$	$2.3x10^6$	$1.7x10^6$

* Too few Algae for an accurate count.

TABLE XVI
BOTTOM SAMPLE

BACTERIA: AEROBIC	1959 SEPT 16	DEC 14
7°C	$4. x10^3$	$1.4x10^6$
20°C	$3.3x10^4$	$8.6x10^5$
37°C	$9.0x10^3$	$3.6x10^4$
ANAEROBIC 37°C	$2.5x10^2$	$2.7x10^3$
COLIFORMS:	$1.1x10^1$	$7.9x10^3$
ALGAE:	$2.0x10^5$	$3.2x10^6$

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MICROBIAL POPULATIONS IN THE DRAYTON VALLEY (#2) SEWAGE LAGOON

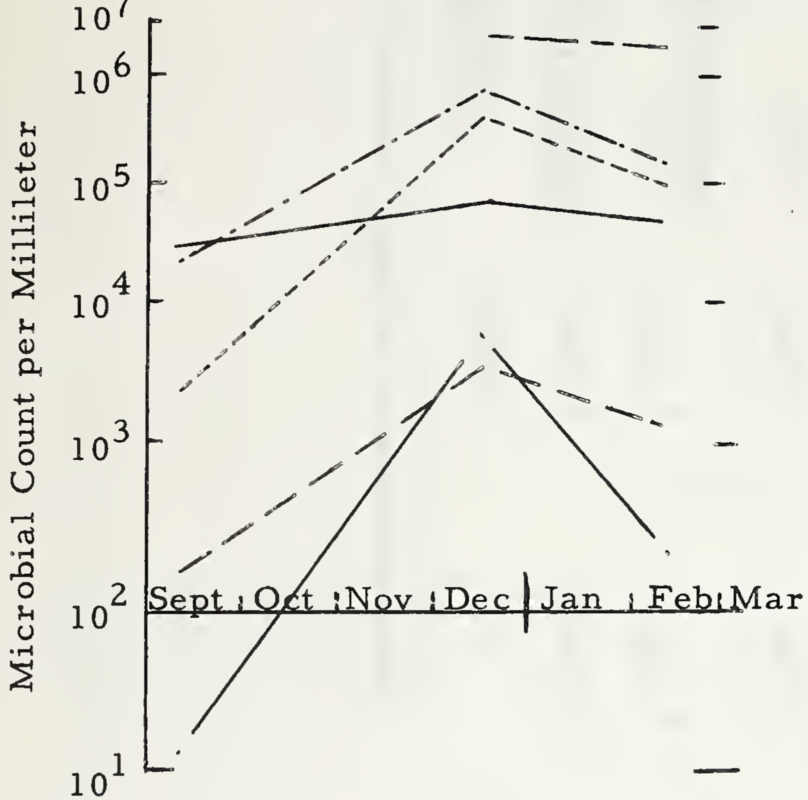


FIGURE 27

TOP SAMPLE

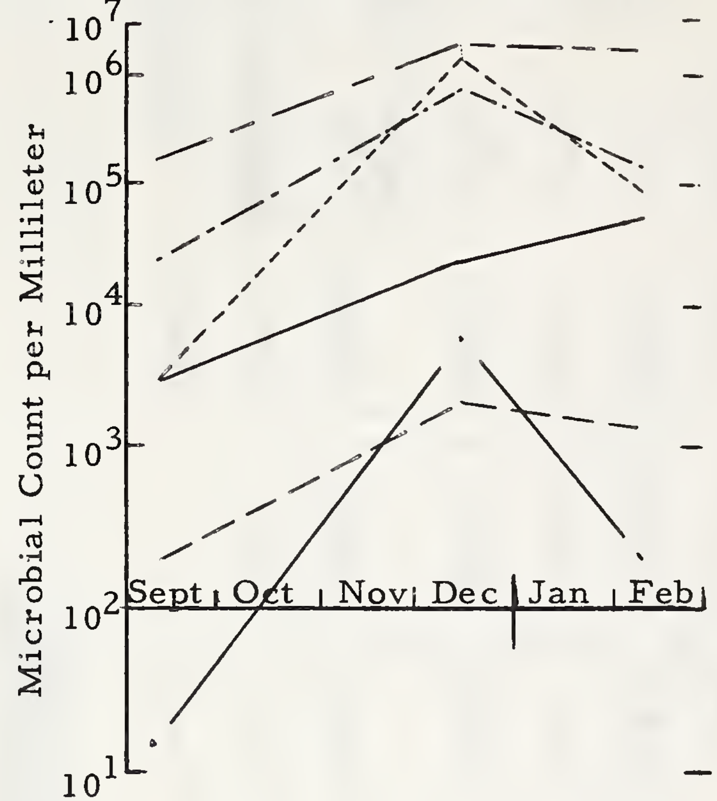


FIGURE 28

BOTTOM SAMPLE

LEGEND

VIABLE BACTERIA COUNT/ml:
(Incubation Temperatures)
Aerobic 7°C - - - - - - - -
20°C -·-·-·-
37°C ———
Anaerobic 37°C — — — —
Coliforms ·———·
TOTAL ALGAE COUNT/ml: —— —— —

MICROBIAL POPULATIONS OF THE DRAYTON VALLEY (#3) SEWAGE LAGOON
(Viable Bacteria Count /ml Total Algae Count /ml)

TABLE XVII
TOP SAMPLE

BACTERIA: AEROBIC	1958 OCT 7	1959 FEB 10	MAR 3	SEPT 16	DEC 14	1960 FEB 9
7°C	3.0×10^{3}	2.2×10^{3}	2.9×10^{5}	8.0×10^{2}	$>3.0 \times 10^{5}$	4.0×10^{5}
20°C	4.0×10^{4}	2.7×10^{4}	1.7×10^{5}	1.0×10^{2}	$>3.0 \times 10^{5}$	5.0×10^{5}
37°C	7.0×10^{2}	1.1×10^{4}	2.7×10^{4}	3.0×10^{2}	$>3.0 \times 10^{4}$	1.2×10^{5}
ANAEROBIC 37°C	$<3.0 \times 10^{4}$	1.1×10^{3}	1.4×10^{4}	4.0×10^{0}	$>3.0 \times 10^{2}$	1.6×10^{4}
COLIFORMS:	2.0×10^{0}	1.7×10^{3}	7.9×10^{3}	2.0×10^{-1}	5.4×10^{4}	3.5×10^{3}
ALGAE:	8.0×10^{5}	*	$>2.5 \times 10^{6}$	*	2.2×10^{6}	4.0×10^{5}

TABLE XVIII
BOTTOM SAMPLE

BACTERIA: AEROBIC	1958 OCT 7	1959 SEPT 16	DEC 14	1960 FEB 9
7°C	1.0×10^{4}	9.0×10^{2}	1.3×10^{5}	2.9×10^{5}
20°C	4.0×10^{4}	7.0×10^{2}	2.3×10^{5}	3.2×10^{5}
37°C	3.0×10^{4}	2.0×10^{4}	1.1×10^{4}	7.6×10^{4}
ANAEROBIC 37°C	$<3.0 \times 10^{4}$	3.0×10^{0}	6.4×10^{2}	7.3×10^{3}
COLIFORMS:	2.0×10^{0}	6.8×10^{0}	$>2.4 \times 10^{3}$	3.5×10^{3}
ALGAE:	4.5×10^{5}	*	2.5×10^{6}	6.4×10^{5}

* Too few Algae for an accurate count.

MICROBIAL POPULATIONS IN THE DRAYTON VALLEY (#3) SEWAGE LAGOON

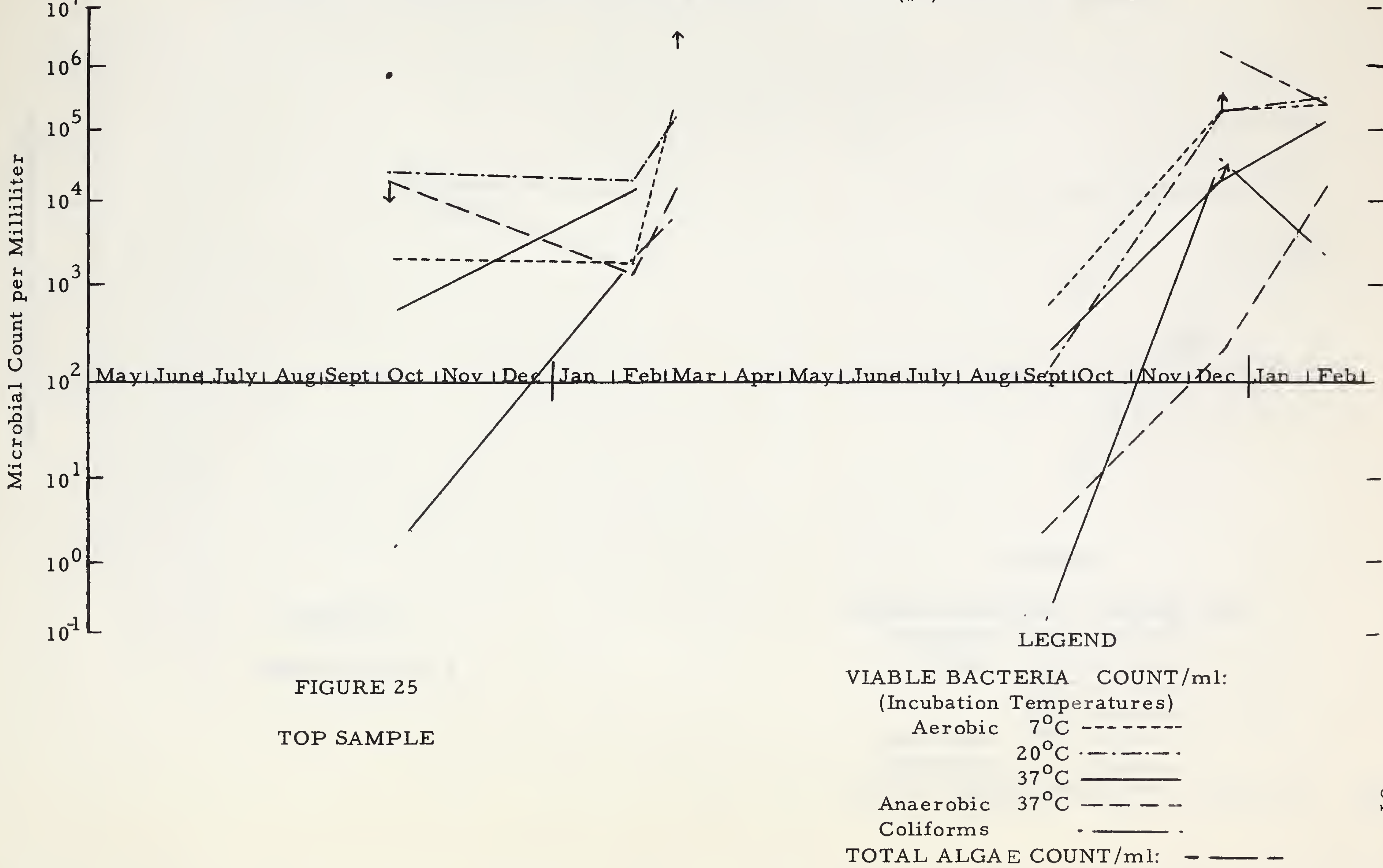


FIGURE 25

TOP SAMPLE

MICROBIAL POPULATIONS IN THE DRAYTON VALLEY (#3) SEWAGE LAGOON

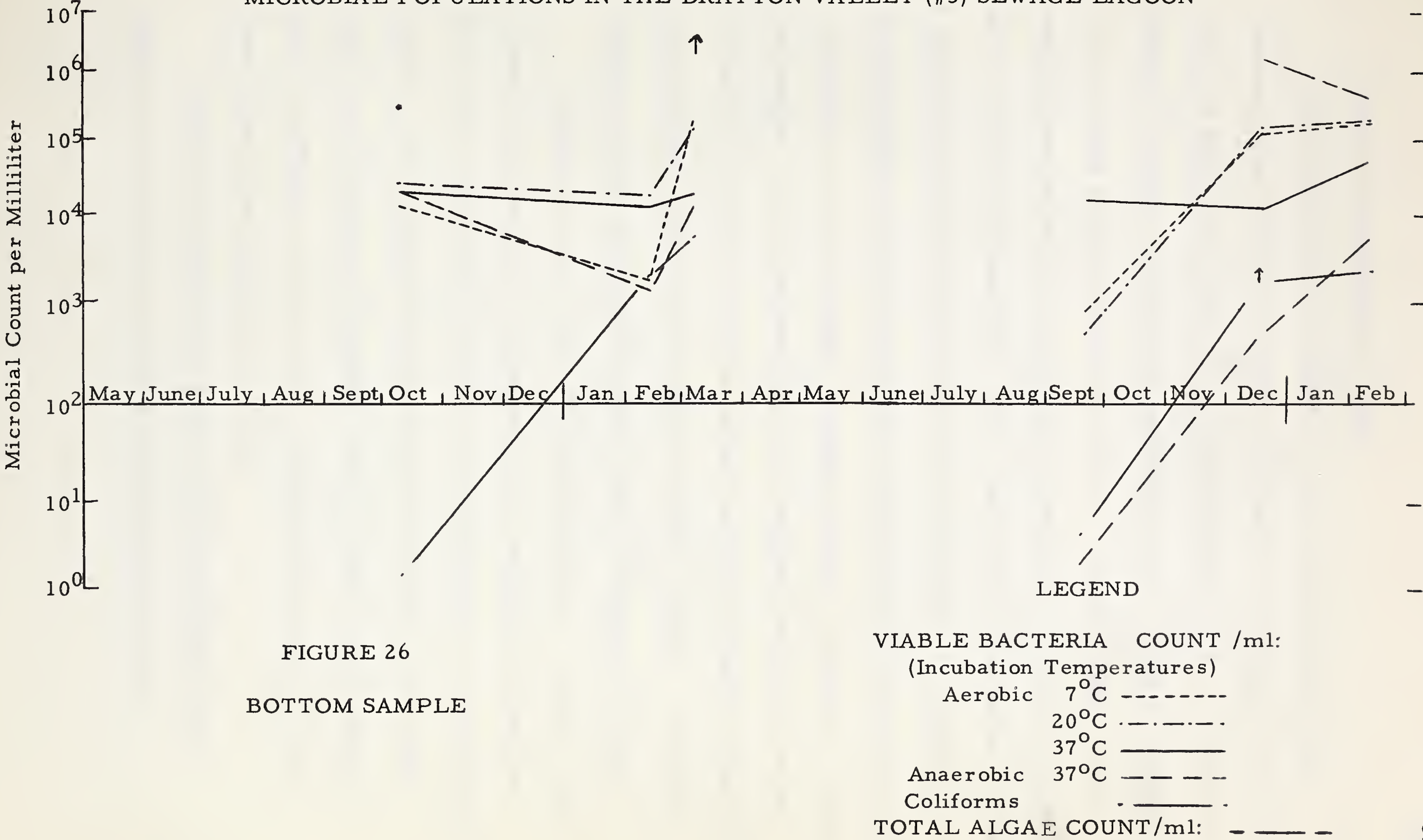


FIGURE 26

BOTTOM SAMPLE

Drayton Valley Sewage Lagoons

Three short detention lagoons in series constitute the sewage treatment plant at Drayton Valley. In November each lagoon is drained to the one foot level so that the operational depths are 4', 4', and 3' for lagoons 1, 2 and 3, though the actual depths are 5', 5' and 4', respectively. The calculated detention times are 51.8, 32.9 and 25.6 days, but for reasons given above the actual detention times are 41.4, 26.3, and 26.7 days respectively (Appendix B). The capacity of the first lagoon is continuously decreasing because it is filling with sludge. The lagoons become storage lagoons during the winter after being drained to the one foot level in November. The first lagoon is stagnant though it continues to receive raw sewage. The subsequent lagoons are stagnant and receive no new nutrients or inocolum of microorganisms until the preceding lagoon fills to overflowing. After the third lagoon is filled, the fluid is allowed to overflow until the following November when each lagoon is drained.

Sampling was carried out at Drayton Valley for 17 months from October /58 to February /60 (Appendix A). During the period from April /59 to August /59 no samples were obtained for a microbiological analysis. Usually top and bottom samples were taken at the outlet retion of each lagoon until drainage when the liquid was too shallow or until the formation of the ice cover. Samples were taken at various times of day from 11:30 AM to 3:30 PM.

From the microbiological point of view the lagoons will be described only during the standard period of routine operation

from November /58 to November /59. The period from November /58 to the middle of February /59 was the period of storage for the whole series of lagoons. No samples were obtained during this period so that the functional capacities of each lagoon are unknown.

The period of continuous overflow began in February /59 and lasted until November /59.

During the winter samples were taken in February and March /59.

Top and bottom samples were taken from lagoon 1 which had a depth of 4 feet and only 1 foot of ice. The February sample had a temperature of $1^{o}C$ and the March sample was $2^{o}C$. No dissolved oxygen was detected by the Winkler method. The pH was 7.5 in both samples.

Only single samples were taken from lagoon 3 since the liquid depth was 2.5 feet and the lagoon was covered by ice 2.0 feet thick. The temperature of the February sample was $0.5^{o}C$ and the March sample was $1^{o}C$. No dissolved oxygen was detected in either sample. The pH was 7.6 in February and 7.7 in March /59.

During the late winter of 1959 the viable bacteria counts remained nearly steady in lagoon 1. The aerobes at $37.5^{o}C$ and at $20^{o}C$ stayed slightly above 10^5/ml. and 10^6/ml. respectively. The aerobes at $7^{o}C$ fluctuated about 10^6/ml. The anaerobes increased during this period from 10^4 to 10^5/ml.

No further samples were taken until the end of the summer of 1959 (September 16/59) so that the functional capacity of the lagoons during the open water period from April to September /59 in unknown.

A top and bottom sample was taken on September 16/59 one and a half months before the lagoons were drained to the one foot level in November /59. On this date samples were taken from all three lagoons for the first time. The samples were taken between 11:15 and 11:45 AM.

The temperature in lagoon 1 was 11^{o}C. Lagoon 2 and 3 both had a temperature of 12^{o}C. The first two lagoons were more alkaline and had the same pH (9.1) whereas lagoon 3 had a pH of 8.55. There was little difference between lagoons with regard to dissolved oxygen, e.g., 1.7 ppm for lagoon 1; 1.4 ppm for lagoon 2; and 1.2 ppm for lagoon 3.

In lagoon 1 only a top sample was taken. The aerobes at 7^{o}C had a count slightly above 10^5/ml. whereas both the 20^{o}C and 37.5^{o}C groups were slightly less than 10^5/ml.

The counts in lagoon 2 were at a lower level except for the anaerobes which remained at 10^2/ml. The aerobes at 7^{o}C were at the 10^3/ml level whereas the 20^{o}C and 37.5^{o}C groups were at the 10^4/ml level. The coliform count was lower (10^1/ml.).

In lagoon 3 the aerobes at 7^{o}C and 20^{o}C were both slightly below 10^3/ml. The aerobes at 37.5^{o}C maintained a high count similar to the previous lagoon at the level of 10^4/ml. Both the anaerobes and the coliforms had the lowest and the same count of 3.5×10^0/ml. In this sample the algae were too few to count accurately.

The extent of stabilization of the microorganisms within each lagoon during this period of standard operation from November /58 to November /59 was greater in each subsequent lagoon.

The stage of stabilization was greater in lagoons 1 and 3 in the summer than during the previous w nter. Lagoon 3 was at a more stabilized state from the microbiological point of view than lagoon 1 and 2.

TABLE XIX

ENVIRONMENTAL FACTORS OBSERVED AT THE HOLDEN SEWAGE LAGOON

Date:	1958 JUNE 4	JUNE 17	JUNE 24	JUNE 25	JUNE 25
Time:	11:00 a.m.	11:00 a.m.	8:00 p.m.	7:00 a.m.	10:30 a.m.
Temp(^{o}C):	17.5	20	19	16	18
D.O(ppm):	4.7	1.9	12.2	3.3	7.0
pH:	9.4	9.1	8.9	8.4	8.4
Weather:	Sunny Cloudy	Cloudy Calm	Clear Windy	Fair Windy	Windy
Depth: *	2.5				

Date:	1958 JULY 4	JULY 18	JULY 30	AUG 15	SEPT 4
Time:	11:15 a.m.	11:15 a.m.	11:05 a.m.	unknown	11:45 a.m.
Temp(^{o}C):	20	24	20	23	14
D.O(ppm):	18.8	6.5	unknown	12.8	unknown
pH:	9.3	9.55	9.6	9.4	9.2
Weather:	Windy	Sunny Windy	Clear Hot	Clear Wind	Fine Wind
Depth:					

Date:	1958 SEPT 24	OCT 21	NOV 18	DEC 2	DEC 16
Time:	10:45 a.m.	11:30 a.m.	10:50 a.m.	11:00 a.m.	11:00 a.m.
Temp(^{o}C):	9	5	0.75	1	1
D.O(ppm):	10.2	12.2	9.7	0	0
pH:	9.1	9.0	9.1	8.8	8.35
Weather:	Fine Windy	Sunny Wind	unknown	Sunny	Sunny
Depth: Ice:			4"	10"	15"
liquid:		<4' *	8"		

*Drawn down to 1' level of liquid.

(continued)

TABLE XIX

ENVIRONMENTAL FACTORS OBSERVED AT THE HOLDEN SEWAGE LAGOON

Date:	1959 JAN 6	FEB 3	MAR 10	MAY 27	SEPT 1	
Time:	11:45 a.m.	11:30 a.m.	12:30 p.m.	Noon	12:15 p.m.	
Temp(^{o}C):	0.5	0.5	unknown	15	14	
D.O(ppm):	0	0	0	unknown	6.6	
pH:	8.1	7.85	7.6	8.9	8.1	
Weather:	unknown	Cloudy	Sunny Warm	unknown	Sunny Wind	
Depth: Ice:	18''	18''	24''			
Liquid:	6''	12''	18'' 3.5' *	1'	3.5'	*

Date:	1960 JAN 6
Time:	11:45 a.m.
Temp(^{o}C):	0.5
D.O(ppm):	0
pH:	8.25
Weather:	Sunny Windy
Depth: Ice:	24''
Liquid:	16''

* Drawn down to 1' level of liquid.

TABLE XX

ENVIRONMENTAL FACTORS OBSERVED AT THE DAYSLAND SEWAGE LAGOON

	1958			
Date:	SEPT 16	OCT 21	NOV 18	DEC 16
Time:	1:30 p.m.	1:15 p.m.	Noon	12:30 p.m.
Temp:(°C):	15.5	11.5	3.0	3.0
D.O(ppm):	0	0	0	0
pH:	7.9	7.8	7.6	7.35
Weather:	Sunny Windy	Sunny Windy	Sunny	Sunny
Depth: Ice:			2.5''	6''
Liquid:	46''	45''	44''	43''

	1959				
Date:	JAN 20	FEB 24	MAR 31	MAY 28	SEPT 1
Time:	1:00 a.m.	2:30 p.m.	1:30 p.m.	1:00 p.m.	1:15 p.m.
Temp(°C):	unknown	3.0	5.0	13.5	13
D.O(ppm):	0	0	0	0	0
pH:	7.4	7.4	7.25	7.7	6.95
Weather:	Sunny Cold	Sunny Warm	Sunny Windy	Overcast Windy	Sunny Windy
Depth: Ice:	9''	12''	0		
Liquid:	42''	41''	40''	38''	34''

	1960
Date:	JAN 27
Time:	Noon
Temp(°C):	1.5
D.O(ppm):	0
pH:	7.55
Weather:	Overcast Calm
Depth: Ice:	7''
Liquid:	30''

TABLE XXI

ENVIRONMENTAL FACTORS OBSERVED AT THE BRUDERHEIM SEWAGE LAGOON

	1958				
Date:	JULY 3	JULY 30	SEPT 4	SEPT 30	NOV 26
Time:	unknown	3:00 p.m.	unknown	unknown	11:00 a.m.
Temp(^{o}C):	unknown	unknown	unknown	unknown	0.25
D.O(ppm) =	0	0	unknown	0	0
pH:	7.6	7.75	unknown	7.8	7.7
Weather:	unknown	unknown	unknown	unknown	Fine Cold
Depth:*	filling	< 4'		< 4' *	1'

	1959				
Date:	JAN 8	FEB 3	MAR 10	JUNE 10	JULY 29
Time:	unknown	3:45 p.m.	2:45 p.m.	1:30 p.m.	2:00 p.m.
Temp(^{o}C):	unknown	0.5	unknown	14	20
D.O(ppm):	0	0	0	0	0
pH:	6.7	6.4	5.95	7.3	7.3
Weather:	unknown	Cloudy Windy	Sunny Warm	Clouded Raining	Sunny Windy
Depth:					
Ice:	unknown	3'	3.5'		
Liquid:		1'	0.5'	> 4'	> 4'

	1959			1960
Date:	AUG 27	OCT 14	DEC 2	JAN 5
Time:	11:00 a.m.	3:00 p.m.	2:30 p.m.	11:45 a.m.
Temp(^{o}C):	14	11	0.75	0.5
D.O(ppm):	0	0	0	0
pH:	7.75	7.6	7.0	6.95
Weather:	Overcast Raining	Fine Warm	Overcast Cool	Overcast Snowing
Depth:				
Ice:			1'	1.5'
Liquid:	> 4'	> 4' *	1.5'	2.0'

*Drawn down to 1' level of liquid.

TABLE XXII

ENVIRONMENTAL FACTORS OBSERVED AT THE LACOMBE SEWAGE LAGOON

	1958				
Date:	JULY 17	JULY 24	JULY 31	AUG 7	AUG 27
Time:	Noon	11:30 a.m.	12:15 p.m.	unknown	11:30 a.m.
Temp(°C):	22	22	22	22	18
D.O(ppm):	25.6	unknown	18.3	12.0	unknown
pH:	10.1	10.0	9.8	9.6	unknown
Weather:	Sunny Calm	Clear	Sunny Calm	Clear Calm	unknown
Depth: *	>5'	>5'	>5'	>5'	>5'
Sunshine(hrs):		80.2	63.9	72.2	204.2

	1958			
Date:	SEPT 10	SEPT 16	OCT 14	NOV 25
Time:	11:00 a.m.	10:30 a.m.	11:45 a.m.	11:45 a.m.
Temp(°C):	16	11.5	4.5	1
D.O(ppm)	4.7	3.4	9.6	0
pH:	9.1	8.9	8.4	8.27
Weather:	Sunny	Sunny Windy	Sunny	Sunny
Depth:	>5'	>5'	>5'	* Ice: 7'' Liquid: 5''
Sunshine:	104.3	27.1	167.3	224.4

	1958	
Date:	DEC 9	DEC 30
Time:	11:30 a.m.	3:30 p.m.
Temp(°C):	1	0.5
D.O(ppm):	0	0
pH:	7.7	7.55
Weather:	Sunny	
Depth: Ice:	15''	12''
Liquid:	8''	12''
Sunshine:	48.3	55.5

* :Drawn down to 1' level of liquid.

(continued)

TABLE XXII

ENVIRONMENTAL FACTORS OBSERVED AT THE LACOMBE SEWAGE LAGOON

	1959				
Date:	JAN 14	FEB 17	MAR 24	JUNE 3	JULY 8
Time:	2:40 p.m.	12:45 p.m.	11:30 a.m.	Noon	1:00 p.m.
Temp(^{O}C):	0.0	0	2.5	16.5	14.1
D.O(ppm):	0	0	0	20.4	unknown
pH:	7.7	7.4	7.3	8.8	9.4
Weather:	Sunny	Sunny	Sunny Warm	unknown	Sunny Windy
Depth: Ice:	18"	15"			
Liquid:	15"	15"	>5'	>5'	>5'
Sunshine:(hr)	39.8	125.2	235.8	526.9	289.9

	1959
Date:	SEPT 1
Time:	4:15 p.m.
Temp:(^{O}C)	15.5
D.O(ppm):	15.3
pH:	8.7
Weather:	Sunny Windy *
Depth:	>5'
Sunshine:	481.0

	1960		
Date:	JAN 13		
Time:	12:15 p.m.		
Temp:(^{O}C)	0.5		
D.O(ppm):	0		
pH:	7.5		
Weather:	Sunny Calm		
Depth:	Ice: 15"	Liquid: 9"	
Sunshine:	425.8 (Total Hours of Bright Sunshine - 31,718 hours)		

* Drawn down to 1' level of liquid.

TABLE XXIII

ENVIRONMENTAL FACTORS OF THE STONY PLAIN (1) SEWAGE LAGOON

	1958
Date:	OCT 27
Time:	2:30 p.m.
Temp(^{o}C):	9
D.O(ppm):	0
pH:	7.6
Weather:	Sunny
Depth:	5'

ENVIRONMENTAL FACTORS OF THE STONY PLAIN (4) SEWAGE LAGOON

	1959	
Date:	AUG 25	DEC 9
Time:	10:30 a.m.	4:00 p.m.
Temp(^{o}C)	14	0.5
D.O(ppm):	8.8	6.3
pH:	8.4	7.75
Weather:	Overcast Calm	Overcast
Depth: Ice:		1'
Liquid:	4'	4.5'

TABLE XXIV

ENVIRONMENTAL FACTORS OBSERVED AT THE STONY PLAIN (3) SEWAGE LAGOON

Date:	1958 AUG 13	AUG 21	SEPT 2	SEPT 30
Time:	3:15 p.m.	6:00 a.m.	10:15 a.m.	11:15 a.m.
Temp(^{o}C):	21.5	16.8	14.5	7
D.O(ppm)	10.5	0	0	17.4
pH:	7.7	7.8	7.6	8.2
Weather:	Clear	unknown	Cloudy	unknown
Depth:	5'	<5'	<5'	<5'

Date:	1958 OCT 27	DEC 9
Time:	2:45 p.m.	unknown
Temp(^{o}C):	8.5	2
D.O(ppm):	0	0
pH:	7.25	7.6
Weather:	Sunny	unknown
Depth: Ice:		8"
Liquid:	>5'	4'

Date:	1959 MAR 3	JUNE 23	AUG 25	DEC 9
Time:	10:45 a.m.	2:45 p.m.	10:00 a.m.	3:45 p.m.
Temp(^{o}C):	2	15	12	3
D.O(ppm):	0	0	8.8	0
pH:	7.5	7.2	7.4	7.5
Weather:	Sunny Warm	Sunny Warm	Overcast Calm	unknown
Depth: Ice:	8"			8"
Liquid:	4'	>5'	>5'	4'

TABLE XXV

ENVIRONMENTAL FACTORS OBSERVED AT THE DRAYTON VALLEY (1) SEWAGE LAGOON

	1958
Date:	OCT 7
Time:	1:30 p.m.
Temp(^{o}C):	11
D.O(ppm):	0.6
pH:	8.9
Weather:	Sunny
Depth: Ice:	
Liquid:	5' *

	1959			
Date:	FEB 10	MAR 3	SEPT 16	DEC 14
Time:	3:15 p.m.	1:30 p.m.	11:45 a.m.	12:30 p.m.
Temp(^{o}C):	1	2	11	1
D.O(ppm):	0	0	1.7	0
pH:	7.45	7.5	9.1	7.5
Weather:	Sunny	Overcast Windy	Overcast	Overcast
Depth: Ice:	1'	1'		1'
Liquid:	4'	4'	5' *	2'

	1960
Date:	FEB 9
Time:	12:30 p.m.
Temp(^{o}C):	0.5
D.O(ppm):	0
pH:	7.65
Weather:	Overcast Snowing
Depth: Ice:	1.5'
Liquid:	1.5'

* Drawn down to 1' level of liquid.

TABLE XXVI

ENVIRONMENTAL FACTORS OBSERVED AT THE DRAYTON VALLEY (2) SEWAGE LAGOON

	1959		1960
Date:	SEPT 16	DEC 14	FEB 9
Time:	11:25 a.m.	12:15 p.m.	Noon
Temp($^{\circ}$C):	12	1	0.5
D.O(ppm):	1.4	0	0
pH:	9.1	7.65	7.9
Weather:	Overcast	Overcast	
Depth: Ice:		1'	1.5'
Liquid:	>5' *	3'	1.5'

* Drawn down to 1' level of liquid.

TABLE XXVII

ENVIRONMENTAL FACTORS OBSERVED
AT THE DRAYTON VALLEY (#3) SEWAGE LAGOON

	1958
Date:	OCT 7
Time:	1:45 p.m.
Temp(°C):	10
D.O(ppm):	11.3
pH:	9.6
Weather:	Sunny
Depth: Ice:	
Liquid:	4' *

	1959			
Date:	FEB 10	MAR 3	SEPT 16	DEC 14
Time:	1:00 p.m.	3:30 p.m.	11:15 a.m.	11:45 a.m.
Temp(°C):	0.5	1	12	1
D.O(ppm):	0	0	1.2	0
pH:	7.6	7.7	8.55	7.95
Weather:	Sunny	Overcast	Overcast	Overcast
Depth: Ice:	2'	2'		1'
Liquid:	2.5'	2.5'	4' *	3'

	1960
Date:	FEB 9
Time:	11:30 a.m.
Temp(°C):	0.5
D.O(ppm):	0
pH:	7.6
Weather:	Overcast
Depth: Ice:	1.5'
Liquid:	3.0'

* Drawn down to 1' level of liquid.

GENERAL DISCUSSION

1. STRUCTURE AND OPERATION OF THE LAGOONS.

The lagoons may be classified according to their structure (Appendix C) and their operational capacities. (Appendix B). None of the lagoons are identical in any of these features. The only common feature is their function to stabilize the organic matter and the microorganisms present within the lagoon.

The lagoons may be classified according to the actual routine of operation (Appendix D) used during the investigation of the standard period which occurred between November/58 and November/59. Only three lagoon systems (Holden, Daysland, Drayton Valley) maintained a standard routine of operation throughout our investigation. Alterations from a standard routine of operation occurred in all others. The third lagoon at Stony Plain was by-passed from August to September/58. Bruderheim lagoon was changed from a storage lagoon in 1958 to an overflow lagoon during the summer of 1959; and drained in April/58 but not April/59. Lacombe lagoon was drained in April/58 so that the overflow occurred from July to November/58; but in 1959 the lagoon was not drained in April so that overflow occurred throughout the open water season.

2. STABILIZATION OF THE MICROORGANISMS.

The influence that the lagoons may have upon the survival and the sedimentation of the microbial populations present within the sewage liquid may be determined by comparing the counts of the microbial populations during the periods of maximum or minimum physico-chemical environmental conditions as occurs in the summer and winter seasons.

Such comparison was possible since the standard period of routine operation of each lagoon occurred from November /58 to November /59 and samples were taken from each lagoon in comparable seasons. Winter samples were taken in the late winter of 1959 from February 17 to March 10/59. During this time the ice cover reached a maximum thickness, hours of sunlight were shortest and the temperature of the lagoon was lowest. Also this was the final stages of storage for storage lagoons and a month before the ice melted from the continuously overflowing lagoons. Summer samples were taken in the late summer of 1959 from August 25 to September 16/59 when there was open water and a continuous overflow of sewage liquid from all but the Holden lagoon. At this time the hours of sunlight were longest and the water temperature of the lagoon approached the maximum for the year.

3. THE COMPARISON OF THE MICROBIAL POPULATIONS OF EACH LAGOON DURING THE STANDARD PERIOD FROM THE LATE WINTER TO LATE SUMMER OF 1959.

1. A Single Lagoon

A. Standard Routine of Operation Throughout the Investigation.

1. HOLDEN

In this long detention lagoon, which is used for raw sewage storage during the winter and summer and is drained before each period, some reduction of the microbial populations occurred within the body of the lagoon. There was a one-tenth reduction of the viable bacteria. The aerobes decreased from 10^6 to 10^5/ml. The anaerobes and the coliforms each decreased from 10^4 to 10^3/ml. The total algae count stayed at 10^6/ml.

2. DAYSLAND

This continuously overflowing lagoon has a short detention period which is continuously becoming shorter due to the deposition of sludge. In the body of the lagoon during the standard period the aerobes maintained a count of 10^6/ml. The anaerobes maintained a steady count (10^5/ml.). The coliforms were reduced from 10^4 to 10^3/ml. The total algae count stayed at 10^6/ml.

B. Routine of Operation Altered During the Investigation.

1. LACOMBE

Lacombe has a long detention lagoon used for storage of raw sewage during the winter and overflow during the summer with drainage each November. Previous to the period of standard operation the lagoon was drained in November and April allowing only a short overflow period from July to November /58. The location of sampling was changed from the body of the lagoon during the winter storage period to the outlet region during the summer overflow of 1959. The aerobes decreased from 10^6 to 10^5/ml. The coliforms maintained a steady count of 10^4/ml. The anaerobes decreased from 10^5 to 10^3/ml. In the summer the total algae count was 10^5/ml.

2. BRUDERHEIM

Like the Lacombe lagoon it is a long detention lagoon used for winter storage and summer overflow with drainage each November. At the

beginning before standard operation, it was used as a storage lagoon like the Holden lagoon. Sampling at the outlet showed that the microbial population remained high throughout the year of standard operation. There was no reduction of the aerobic bacteria. (10^6/ml.). The anaerobes decreased from 10^6 to 10^3/ml. The coliforms decreased from 10^4 to 10^3/ml. The algae were at the highest count of any lagoon; greater than 10^8/ml.

II. A SERIES OF LAGOONS

A. Routine of Operation Altered During the Investigation.

1. STONY PLAIN

There are a series of three short detention lagoons which continuously overflow. The first lagoon is a sludge pit which is continuously filling with sludge. The third lagoon was stagnant until the beginning of the period of standard operation. In the third lagoon there was no reduction of the aerobes (10^6/ml) and the anaerobic count remained at 10^4/ml. The coliforms decreased from 10^5 to 10^4/ml. The total count of algae was 10^{5-7}/ml.

2. DRAYTON VALLEY

Stabilization of the microorganisms occurs in three stages in this series of short detention lagoons. During the period of standard operation this system was used for early winter storage and late winter and summer overflow. The lagoons are drained each November so that the length of the storage period for each lagoon during the early winter depends upon the time required to fill each lagoon to overflowing.

There were insufficient samples from lagoon 2 to show a comparison.

The stabilization of microorganisms which occurred between lagoon 1 in the winter and lagoon 3 in the summer was as follows:

The aerobic bacteria decreased from 10^6 to 10^4/ml. (Both the 7°C and the 20°C groups decreased from 10^6 to 10^2/ml. The 37.5°C group decreased from 10^5 to 10^4/ml.) The anaerobic bacteria decreased from 10^5 to 3.5×10^0/ml. The Most Probable Number of coliforms decreased from 10^4 to 3.5×10^0/ml. The total count of algae remained near 10^6/ml.

SUMMARY

The efficiency of stabilization of microorganisms in the various lagoon systems which were investigated may be summarized as follows:

1. There is no reduction in the number of viable aerobic bacteria in a continuously overflowing lagoon system which consists of a single or a series of short detention lagoons. (Daysland, Stony Plain)

2. The least reduction in the number of viable aerobic bacteria occurs in a lagoon system which consists of a single long detention lagoon used for winter and summer storage. (Holden)

3. The greatest reduction in the number of viable aerobic bacteria occurs in a series of short detention lagoons used for storage in early winter and allowed to overflow through the late winter and summer. (Drayton Valley)

4. When single long detention lagoons are used for winter storage and summer overflow and the lagoons have a different structural design and capacity (Appendix B) the greatest reduction in the number of aerobic bacteria occurs in the lagoon with the greatest surface area. (Lacombe, Bruderheim)

5. There is no reduction in the number of viable anaerobic bacteria in a continuously overflowing lagoon system which consists of a single or a series of short detention lagoons. (Daysland, Stony Plain)

6. The least-reduction in the number of viable anaerobic bacteria occurs in a lagoon system which consists of a single long detention lagoon used for winter storage and summer storage or summer overflow. (Holden, Bruderheim, Lacombe)

7. The greatest reduction in the number of viable anaerobic bacteria occurs in a series of short detention lagoons used for storage in early winter and allowed to overflow through the late winter and summer. (Drayton Valley)

8. The greatest reduction in the number of coliform bacteria occurs in a series of short detention lagoons used for storage in early winter and allowed to overflow through the late winter and summer. (Drayton Valley) Minimal reduction occurs in all other types of lagoon systems.

9. In a series of continuously overflowing lagoons the reduction in the number of viable aerobic, anaerobic and coliform bacteria is greatest when an optimal detention time is employed for each lagoon.

10. Based on Public Health Standards for the Most Probable Number of coliforms allowable in drinking water supplies the effluent from all of the lagoon systems is not satisfactory.

11. The total count of algae remains high in all lagoons winter (under the ice) and summer.

12. The culture method employed in this investigation revealed no Salmonella or Shigella.

APPENDIX A

THE SCHEDULE OF THE SEWAGE SAMPLES WHICH WERE COLLECTED FROM EACH LAGOON

Year: 1958

Month:	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
1. Holden	20	4 17 24 25	4 18 30	15	4 24	21	18	2 16
2. Daysland					16	21	18	16
3. Bruderheim			3 30		4 30		26	
4. Lacombe			17 24 31	7 27	10 16	14	25	9 30
5. Stony Plain				13 21	2 30	27		9
6. Drayton Valley						7		

(Continued)

APPENDIX A

THE SCHEDULE OF THE SEWAGE SAMPLES WHICH WERE COLLECTED FROM EACH LAGOON

Year:	1959												1960	
Month:	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.
1. Holden	6	3	10		27				1				6	
2. Daysland	20	24	31		28				1				27	
3. Bruderheim	8	3	10			10	29	27		14		2	5	
4. Lacombe	14	17	24			3	8		1				13	
5. Stony Plain			3			23		25				9		
6. Drayton Valley		10	3						16			14		9

APPENDIX B

CHARACTERS OF THE LAGOON

LAGOON	POPULATION	SEWAGE FLOW (gpd)	SURFACE ACREAGE (Acres)	DEPTH: Maximum (Feet)	Used (Feet)	VOLUME CAPACITY (mg)
1. Holden	450	28,500	7.2	4	3	7.82
2. Daysland	350	15,040	0.0575	6	4-2.5	0.09345
3. Bruderheim	220	20,000	3.67	4	3	4.0
4. Lacombe	2835	110,600	16.64	5	4	22.6
5. Stony Plain	1040	75,900	1. 0.0517	5	?	0.0703
			2. 0.0517	5	4	0.0703
			3. 0.145	5	4	0.1076
			4. 9.0	6	5	14.19
6. Drayton Valley	2800	241,900	1. 9.2	5	4	12.5
			2. 5.85	5	4	7.95
			3. 7.84	4	3	8.53

(Continued)

[illegible]

APPENDIX B

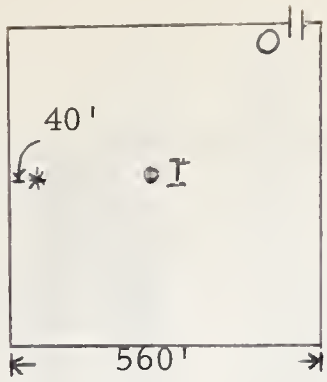
CHARACTERS OF THE LAGOON

LAGOON	DETENTION TIME: (Days) Based on: Maximum Depth	Actual Used Depth	Operation in Standard Period
1. Holden	274	205.5	150; 210
2. Daysland	6.2	(4.1-2.6)	(3.4 - 2.9)
3. Bruderheim	200	150	150
4. Lacombe	204.4	164	150
5. Stony Plain	0.93 0.93 2.6 187 191.46	156	
6. Drayton Valley	51.8 32.9 35.6 120.3	41.4 26.3 26.7	41.4 67.7 94.4

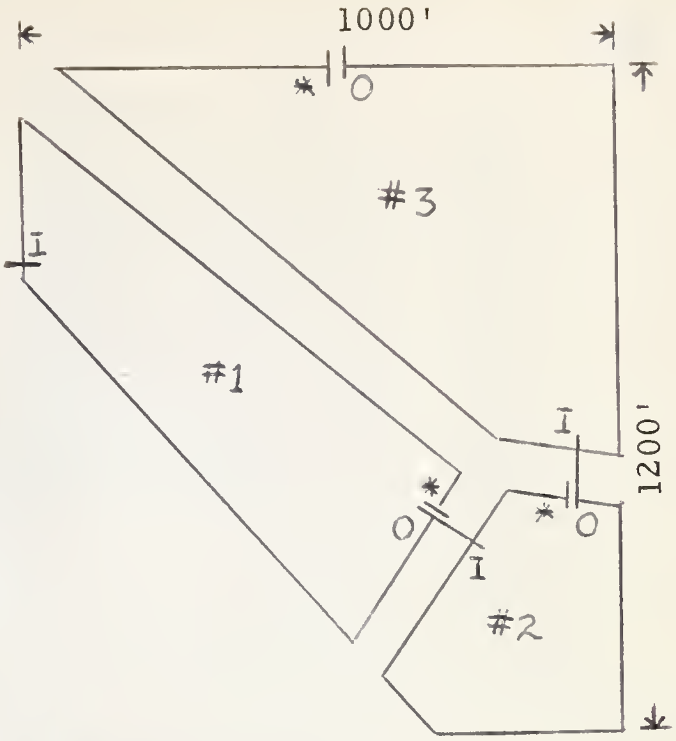
APPENDIX C

DIMENSIONS OF THE SEWAGE LAGOONS

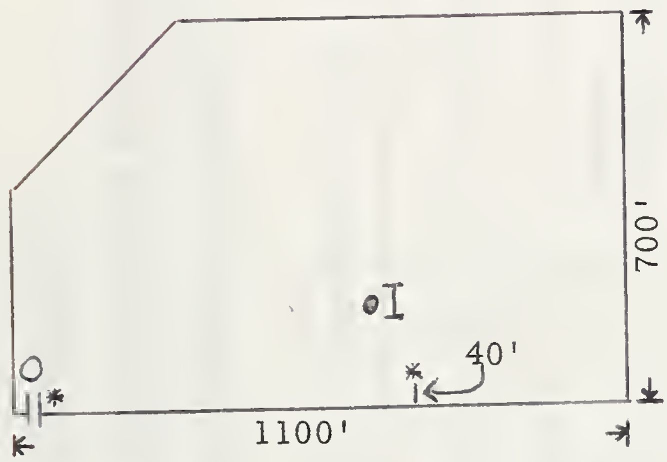
LEGEND: Inlet = I
Outlet = O
Sample = *



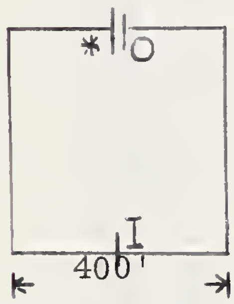
Holden



Drayton Valley

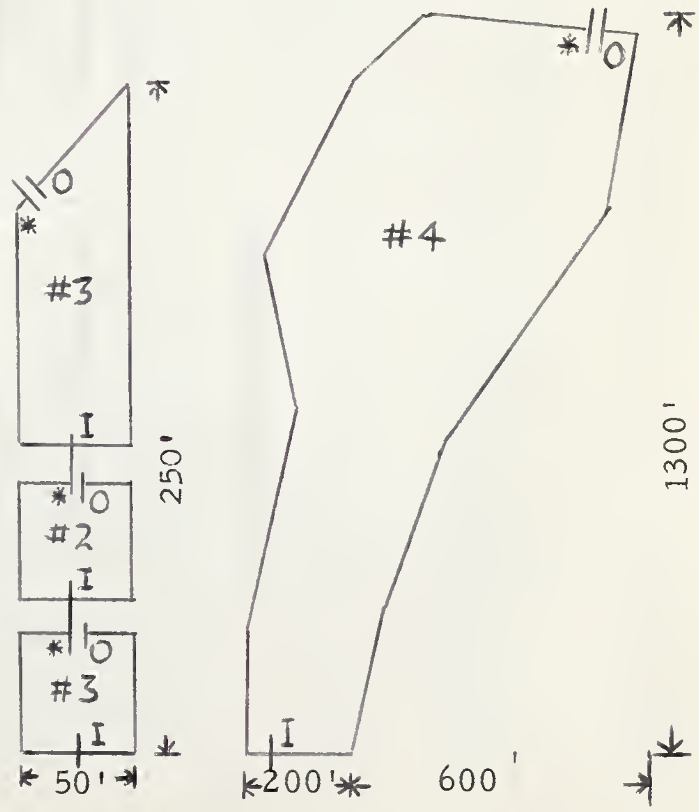


Lacombe



Bruderheim

Daysland



Stony Plain

APPENDIX D - 1

CLASSIFICATION OF THE LAGOONS BASED UPON THE STANDARD ROUTINE OF OPERATION.

<table>
<tr><td>1. Storage Lagoon:

Period:
(Winter and Summer)</td><td colspan="2">2. Storage and Overflow Lagoon:

(Winter) (Summer)</td><td>3. Overflow Lagoon:

(Yearly)</td></tr>
<tr><td colspan="2">i. Long Detention.</td><td colspan="2">ii. Short Detention.</td></tr>
<tr><td colspan="2">A. Single Lagoon:</td><td colspan="2">B. Series of Lagoons:</td></tr>
<tr><td>1. Holden.
2. Stony Plain #4.</td><td>1. Bruderheim.
2. Lacombe.</td><td>1. Drayton Valley 1, 2, 3.</td><td>1. Stony Plain.
2. *Daysland.</td></tr>
</table>

* To a Natural Slough.

APPENDIX D-2

THE SCHEDULE OF THE ROUTINE OF OPERATION OF EACH LAGOON DURING THE INVESTIGATION.

	Apr May June July Aug Sept Oct	Nov Dec Jan Feb Mar	Apr May June July Aug Sept Oct	Nov Dec Jan Feb
HOLDEN	D Summer Storage	D Winter Storage	D Summer Storage	D Winter Storage
LACOMBE	D Summer Storage and Over-flow	D Winter Storage	Summer Overflow	D Winter Storage
BRUDERHEIM	D Summer Storage	D Winter Storage	Summer Overflow	D Winter Storage
DRAYTON VALLEY 1.	Summer Overflow	D. W. S. Winter and Summer Overflow	Winter and Summer Overflow	D. W. S. Overflow to 3 (By-passed)
2.	Summer Overflow	D. Winter Storage Winter and Summer Overflow	Winter and Summer Overflow	D. W. S.
3.	Summer Overflow	D. Winter Storage Winter and Summer Overflow	Winter and Summer Overflow	D. W. S. Overflow from 1
STONY PLAIN 3.	(By-passed) Summer continuous Overflow	Summer continuous Overflow		
DAYSLAND	Continious Overflow			

Standard Period during which there was a standard routine of operation.

(W.S. - Winter Storage)

D. - Drainage of the Lagoon to the one foot level.

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE HOLDEN SEWAGE LAGOON

1958	OPEN WATER
June 4	Chlorella
June 17	Chlorella Merismopedia Staurustrum Chlamydomonas
June 24	Chlorella
June 25	Chlorella
July 4	Chlorella Asterionella
July 18	Chlorella
July 30	Chlorella Selenastrum
Aug 15	Chlorella Scenedesmus
Sept 4	Scenedesmus Chlorella Merismopedia Chlorococcum
Sept 24	Scenedesmus
Oct 21	Chlorella Scenedesmus

1958	ICE COVER
Nov 18	Chlorella Scenedesmus Synedra Ulothrix
Dec 2	Chlorella Anabaena Scenedesmus
Dec 16	Scenedesmus Chlorella Crucigenia Ankistrodesmus Anabaena
1959	
Jan 6	Scenedesmus Chlorella
Feb 3	Ankistrodesmus Scenedesmus
Mar 10	None recognizable A milky fluid

1959	OPEN WATER
May 27	Chlorella Crucigenia Scenedesmus Anabaena
Sept 1	Scenedesmus Chlorella
1960	
Jan 6	Microcystis Ankistrodesmus Crucigenia Polytoma Anabaena Navicula
	OPEN WATER
Apr 27	Microcystis Crucigenia Ankistrodesmus Scenedesmus Chlorella Anabaena

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE HOLDEN SEWAGE LAGOON

1958	OPEN WATER	1958	ICE COVER	1959	OPEN WATER
June 4	Chlorella	Nov 18	Chlorella	May 27	Chlorella
			Scenedesmus		Crucigenia
June 17	Chlorella		Synedra		Scenedesmus
	Merismopedia		Ulothrix		Anabaena
	Staurustrum				
	Chlamydomonas	Dec 2	Chlorella	Sept 1	Scenedesmus
			Anabaena		Chlorella
June 24	Chlorella		Scenedesmus	1960	
				Jan 6	Microcystis
June 25	Chlorella	Dec 16	Scenedesmus		Ankistrodesmus
			Chlorella		Crucigenia
July 4	Chlorella		Crucigenia		Polytoma
	Asterionella		Ankistrodesmus		Anabaena
			Anabaena		Navicula
July 18	Chlorella				
		1959			OPEN WATER
July 30	Chlorella	Jan 6	Scenedesmus	Apr 27	Microcystis
	Selenastrum		Chlorella		Crucigenia
					Ankistrodesmus
Aug 15	Chlorella	Feb 3	Ankistrodesmus		Scenedesmus
	Scenedesmus		Scenedesmus		Chlorella
					Anabaena
Sept 4	Scenedesmus	Mar 10	None recognizable		
	Chlorella		A milky fluid		
	Merismopedia				
	Chlorococcum				
Sept 24	Scenedesmus				
Oct 21	Chlorella				
	Scenedesmus				

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE DAYSLAND SEWAGE LAGOON

1958		OPEN WATER
Sept	16	Anabaena Chlamydomonas
Oct	21	Anabaena Chlamydomonas
		ICE COVER
Nov	18	None recognizable
Dec	16	Crucigenia Ankistrodesmus
1959		
Jan	20	Crucigenia Ankistrodesmus
Feb	24	Crucigenia Ankistrodesmus Anabaena
1959		OPEN WATER
Mar	31	Crucigenia Ankistrodesmus Anabaena
May	28	Chlorella Ankistrodesmus Crucigenia
Sept	1	Crucigenia Anabaena Chlorella Ankistrodesmus
1960		ICE COVER
Jan	27	Microcystis Ankistrodesmus Anabaena

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE BRUDERHEIM SEWAGE.

1958	OPEN WATER
July 3	Chlorella
July 30	Chlorella
Sept 4	Chlorella
Sept 30	Chlorella
	ICE COVER
Nov 26	Anabaena Chlorella Crucigenia
1959	
Jan 8	Anabaena
Feb 3	Ankistrodesmus Crucigenia Anabaena
Mar 10	Ankistrodesmus Anabaena

1959	OPEN WATER
June 10	Crucigenia Anabaena
July 29	Ankistrodesmus Chroococcus Merismopedia Crucigenia Microcystis
Aug 27	Dictyosphaerium Gleocystis Franceia Crucigenia Chroococcus
Oct 14	Chlorella Pandorina Ankistrodesmus Crucigenia Merismopedia Anabaena Polytoma Chroococcus

1959	ICE COVER
Dec 2	Polytoma Crucigenia Merismopedia Ankistrodesmus Anabaena
1960	
Jan 5	Polytoma Anabaena Microcystis Chlorella Merismopedia Ankistrodesmus Crucigenia Pandorina

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE LACOMBE SEWAGE LAGOON

1958		OPEN WATER
July	17	Chlorella Selenastrium Phlormidium
July	24	Chlorella Selenastrum
July	31	Scenedesmus Merismopedia
Aug	7	Scenedesmus
Sept	10	Scenedesmus
Sept	16	Scenedesmus
Oct	14	Scenedesmus Chlorella Chlorococcum

1958		ICE COVER
Nov	18	Scenedesmus Crucigenia Merismopedia Rhabdoderma
Dec	9	Ankistrodesmus Scenedesmus
Dec	30	Crucigenia
1959		
Jan	14	Crucigenia Ankistrodesmus
		OPEN WATER
Mar	24	Crucigenia
June	3	Scenedesmus Crucigenia
July	8	Scenedesmus
Sept	1	Scenedesmus Ankistrodesmus
		ICE COVER
1960		
Jan	13	Microcystis Polytoma

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE STONY PLAIN SEWAGE LAGOONS

LAGOON 3

1958		OPEN WATER
Aug	13	Chlorella
Aug	21	Chlorella
Sept	2	Chlamydomonas Euglena
Sept	30	Euglena
Oct	27	None recognizable
		ICE COVER
Dec	9	Ankistrodesmus
1959		OPEN WATER
Aug	25	Ankistrodesmus Anabaena Microcystis
		ICE COVER
Dec	9	Microcystis Ankistrodesmus Crucigenia Chlorella Anabaena Chroococcus

LAGOON 1

1958		
		OPEN WATER
Oct	27	Debris

LAGOON 4

1959		OPEN WATER
Aug	25	No recognizable algae
		ICE COVER
Dec	9	Microcystis Trachelomonas Anabaena Chlorella Crucigenia Ankistrodesmus

APPENDIX E

THE DOMINANT GENERA OF ALGAE IDENTIFIED IN THE DRAYTON VALLEY LAGOONS.

LAGOON 1		LAGOON 2		LAGOON 3	
1958	OPEN WATER			1958	
Oct 7	Scenedesmus Euglena			Oct 7	Scenedesmus
1959	ICE COVER			1959	
Feb 9	Scenedesmus Ankistrodesmus			Feb 9	None seen
Mar 3	Ankistrodesmus Crucigenia			Mar 3	Crucigenia Ankistrodesmus
	OPEN WATER	1959	OPEN WATER		OPEN WATER
Sept 16	Chlorella Scenedesmus	Sep 16	Spirogyra	Sept 16	None seen
	ICE COVER		ICE COVER		ICE COVER
Dec 14	Chlorella Microcystis Ankistrodesmus Protococcus Anabaena Chlamydomonas Scenedesmus	Dec 14	Microcystis Ankistrodesmus Anabaena Chlorella Scenedesmus Crucigenia Protococcus	Dec 14	Microcystis Ankistrodesmus Anabaena Chlorella Scenedesmus
1960		1960		1960	
Feb 9	Microcystis Ankistrodesmus Crucigenia Scenedesmus	Feb 9	Microcystis Ankistrodesmus Crucigenia	Feb 9	Microcystis Ankistrodesmus Anabaena Chlorella

APPENDIX E

PROTOZOA AND CRUSTACEA

DATE:

HOLDEN

1958		
June	17	Paramecium
June	24	Paramecium, Daphnia
June	25	Paramecium, Daphnia
July	4	Paramecium, Daphnia
July	18	protozoa
July	30	protozoa
Sept	4	Paramecium, amoeba
Nov	18	Daphnia

BRUDERHEIM

1958		
Sept	4	Some protozoa - Paramecium ?

LACOMBE

1958		
July	17	Paramecium
July	24	protozoa

STONY PLAIN LAGOON 3.

1958		
Aug	13	Daphnia
Aug	21	Daphnia

BIBLIOGRAPHY

American Public Health Association.
Standard Methods for the Examination of Water, Sewage, and Industrial Wastes. page 385., Tenth Edition. 1955.

Fitzgerald, G. P., Rochlich, G. A. An Evaluation of Stabilization Literature. Sewage and Industrial Wastes Journal. 30:1213, 1958.

Hermann, E. R., Gloyna, E. F., Development of Design Criteria for Waste Stabilization Ponds. Final Report to the Atomic Energy Commission. March 1, 1957.

Lackie, T. H. Experiences with Sewage Lagoons in the Prairie Provinces. The Municipal Utilities Magazine. Page 24, March 1957.

Masato Kaneshige, H. Stabilization Ponds for the Removal of Algal Nutrients from Sewage and Sewage Effluents. Doctoral Thesis University of Wisconsin. 1959.

McKinney, R. E. Activity of Microorganisms in Organic Waste Disposal. II. Aerobic Process. Applied Microbiology. 5:167, 1956.

Odum, P. O., (Odum, H. T.). Fundamentals of Ecology., W. B. Saunders, Philadelphia, 1959.

Schaeferr, J. G. The Treatment of Sewage by Lagooning. Can. J. of Public Health. 48:438, 1957.

Wennstrom, M. Oxidation Ponds in Sweden. Lunds Universitets Arrskrift, N. F. Avd. 2, 51, 1955.

ZoBell, E.; Sisler, F. D.; and Oppenheimer, C. H. 1953. Evidence of Biochemical heating of Lake Meade Mud. J. Sed. Petrol., 23: 13-17.